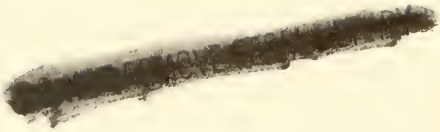

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(Vol. XV.—July, 1886.)

ADDRESS

AT THE ANNUAL CONVENTION, AT DENVER, COLO., JULY 2D, 1886,

BY

HENRY FLAD, President Am. Soc. C. E.

The field of engineering science has of late years become so extensive, that the task imposed on your President of giving a summary of engineering progress during the year is one of considerable magnitude. To make such a summary exhaustive, the records of all civilized countries would have to be searched, and the merits of new methods and appliances carefully weighed, so that only those which have proved, or given promise, of real value may be brought to your notice.

It would be impracticable within the limits of this address to even enumerate all the important engineering works commenced or completed during the year; and to present simply a statement of the dimensions and cost of such works would be of slight interest or benefit to the Members of the Society. I have therefore concluded it would be preferable that I should mention some of the most important works only, and devote a portion of this address to a statement of my individual views on

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such other matters as I judge to be for the well-being and progress of the profession. Even if some of my views should be shared by but few of those to whom I speak, no harm can ensue, as—very properly—the Society is not responsible for the individual opinions of its Members. Furthermore, a departure from precedent to this extent, and from what may be termed the strict construction of the By-Laws, will doubtless lead to more general consideration of the subjects to which I refer.

There is another point on which I propose to depart from the beaten path. Instead of giving the greatest prominence to those works of the engineer which never fail to excite general admiration, by being either the largest or the most difficult, or perhaps the most expensive, I propose to give the first consideration to that part of the work of the engineer which more directly influences the health and comfort of the human race.

I will therefore commence by referring to municipal engineering, by which I mean those branches of engineering which provide abundant and pure water, good streets, and safe buildings, and which keep pestilence from our dwellings by providing for the prompt removal of all offal and *debris*, or by applying proper means for destroying their power to work harm.

A liberal supply of wholesome water is an essential condition for health and comfort. This has been recognized most fully in our own country. Even the smallest towns are erecting water-works, and the large cities are either extending their existing works, or are engaged in investigating the best method for improving, as well as for increasing their supply of water.

When the planning and construction of works of this kind is entrusted to experienced and skillful engineers, as is generally the case in our large cities, and when the usefulness of the engineer is not impaired by the interference of politicians, or of another class of men who may be called amateur engineers, the works are substantially constructed with a view to economical operation, and with due regard to the necessities of the future.

In the smaller cities or towns the mode generally adopted is for one of the many water-work companies or syndicates to undertake the planning and construction of water-works under a contract by which they guarantee a number of fire streams of a fixed height at a certain price

per annum, and also to supply water to the inhabitants at a rate agreed upon. But as the engineer in charge of the municipal work too often has no special knowledge of hydraulic engineering, it is but natural that in most cases the lowest bid will be accepted, and just as natural that the company or syndicate which obtains the franchise for the construction and operation of the works should plan them with a view mainly to cheapness in first cost, and without any regard either to the quality of the water to be furnished, or to the permanency of the works. That under such a system many of the water-works of our smaller cities should be more or less failures, is hardly to be wondered at.

There are a number of companies in this business which have a reputation to uphold, and employ competent engineers to plan and to construct the works for which they contract; but unless the city authorities should possess greater wisdom and knowledge of hydraulic works than they are ordinarily gifted with, some speculating syndicate will underbid, as it safely may, the responsible firm or company, and by building poor works inflict a lasting injury on the community.

Of new devices used in operating water-works, I may call attention to the æration of water, by means of air introduced into the pipes under pressure, for the purpose of destroying the organic germs which otherwise might affect the salubrity or taste of the water.

A new method of investigating the purity of potable water has also been introduced. It consists in observing the colonies of microbes which are produced in gelatine that has previously been sterilized. This method was first used in Berlin, and probably leads to more correct conclusions in regard to the salubrity of the water than any chemical analysis.

As regards cleaning the water from solid matter carried in suspension, our country cannot claim to have reached the high standard that obtains in other countries. American practice, in cases where the water is taken from turbid streams, generally provides only for removing so much of the material held in suspension as will subside during a certain period of quiescence in settling basins.

Filtration, so largely used in England and on the Continent, is used here in but few instances. One reason why it is not more generally adopted, probably lies in the fact that the quantity of water consumed *per capita* in this country is largely in excess of all legitimate requirements. Of late years the quantity *per capita* has been reduced by

various means adopted to prevent waste. If efforts in this direction are continued, and are reasonably successful, measures for improving the quality of our potable water will probably be more generally adopted.

The most important and extensive works for the supply of water which are being carried on at present, are those of New York in the United States and Liverpool in England. The New York works are intended to provide an ultimate daily supply of 320 000 000 gallons. The main features are a masonry dam, 178 feet above the bed of the stream and 1 300 feet in length, forming a lake, which will contain 3 200 000 000 gallons. As the masonry of the dam must be sunk more than 100 feet to reach solid rock foundation, its total height will be nearly 300 feet, and its width at the bottom about 200 feet. The aqueduct which is to carry the water to the Central Park Reservoir is to be 31 miles in length, and of an average diameter of 14 feet. It will cross the Harlem River by an inverted syphon, 150 feet below tide level. The construction of the aqueduct is rapidly progressing.

Of similar character, and of hardly less magnitude, are the works for the supply of water to Liverpool. The Vrynwy Dam, of Cyclopean masonry, is to be 136 feet high in the center, 1 258 feet in length, and 117 feet thick in its widest part, and the impounded water will cover 1 118 acres. The aqueduct will be 35 miles in length.

The work of the engineer next in importance, if its effect on health be made the criterion, consists in providing for the removal of all refuse matter which if allowed to remain would affect the health or comfort of the community. The need of works of this kind has become so fully recognized of late years, that their construction has grown into a special branch of engineering.

The removal and disposal of human *excreta*, and of the waste water from dwellings and factories, present greater difficulties than that of any other kind of refuse. Both scientific attainments and experience are required in the engineer who undertakes to select that system of sewerage which is best adapted to local conditions and requirements. The system of carriage by water is evidently the only one practicable in a country where the water-closet is so generally used as in the United States.

Whether sewage proper should be taken into the conduits which, in most cities, it is necessary to construct to carry off storm water, or

whether it should be carried off separately—in other words, whether a combined or separate system of sewerage should, for any particular city or town, be chosen—cannot be properly determined without thoroughly weighing the advantages and disadvantages of either system, as applied to the particular place requiring the improvement. To insist that one of these systems should be exclusively used in all cases is, in my opinion, a position which the engineer ought not to assume.

With the combined system, the only rational method for the final disposal of sewage consists in its discharge into large bodies of water in motion, except, perhaps, where extensive tracts of sandy soil are available.

Instead of entering into a discussion of the different methods used for finally disposing of the sewage under the separate system, I will state that, in my judgment, the filtration of sewage, by allowing it to flow over large areas of under-drained land (as is practiced with perfect success in many towns in England, and which has also been introduced at the City of Pullman, Ill.) is the most certain and most generally applicable method.

The appliances for receiving the sewage and conducting it from the houses—or what may be designated as plumbing fixtures—have lately been receiving much more attention than formerly, and our people are slowly learning, some of them by dire experience, that in building lwellings they should look to perfect design and workmanship in the xecution of plumbing work, rather than to its cheapness, if they desire) secure healthy homes.

Speaking of the disposal of refuse matter, I will mention that the lrning of street sweepings and offal, in ovens constructed for the purlse, is successfully and economically carried on at Leeds and other pces in England, and express the hope that the example will soon be fcowed in our own country. But the burning of street sweepings can beconomically carried out only when the pavements are constructed of merial which is not readily abraded by the traffic.

he necessity of procuring pavements of this kind is fully recogniz, and the streets of Paris, London, Berlin, Vienna, New York, BostonChicago, St. Louis, Baltimore, Cincinnati and Washington, are nowearly all being paved with the same kinds of material, and under almo identical specifications. Granite blocks, wooden blocks and

monolithic asphaltum are almost exclusively used in the principal streets of these cities. The granite pavement is the most durable and requires the least repairs; the monolithic asphaltum takes precedence from a sanitary point of view; and the pavement made of blocks of wood, as lately constructed, is preferred by some on account of its being easiest on horses and least noisy. But it still remains for the engineer to devise a pavement, durable and smooth, for use on streets where the traffic is not heavy enough to require granite, or where the cost of either of the two other pavements above mentioned is too great to justify their application.

Macadam pavements, when good stone can be obtained, will, under proper treatment, give a smooth surface, agreeable for travel, provided they are kept in first-class order by the immediate repair of any defect. But this is a condition which can hardly be realized in this country on account of the high price of labor.

Street pavements of hard-burnt brick are now being tried on a large scale in a number of towns in Illinois. At Bloomington such a pavement has been in use since 1876. Blocks composed of coal tar, pitch and sand, and called ceramite, have been used for street pavements at Buda-Pesth since 1881. Both these pavements are laid in a similar manner.

A street pavement of round cedar blocks has been largely introduced in Western cities of late years, but can hardly be considered to fill the conditions required for a good pavement, on account of the unequal wear of the sap and heart-wood.

Among the things which affect the health and comfort of the inhabitants of cities using bituminous coal, is the smoke from factories and dwellings. Many appliances for smoke prevention have been devised, some of which are reasonably successful. Their application mitigates the evil, if it does not wholly remove it; but it is to be hoped that the experience gained at points where natural gas has been found and applied to heating purposes, and the late improvements in the manufacture of heating gas, will before long lead our people to abandon the primitive mode of heating with solid fuel now in vogue, and thus abate the smoke nuisance.

A new problem is pressing itself upon the attention of the municipal engineer—one that presents special difficulties, and will require highest

endeavors to satisfactorily solve. This is the proper method of arranging and carrying the numerous wires required for the electrical appliances which are now used in our cities and towns. In the larger cities, where space is limited and the purposes to which electricity is applied are various, necessitating the employment of all kinds of electrical currents, many of which act injuriously upon each other, the electrical difficulties to be overcome are great, and by many are considered to be of such magnitude as to forbid the use of routes or ways in common. In the larger cities the public demand that the wires shall be placed underground, and undoubtedly they must be so placed to a greater or 'ess extent.

The electrical difficulties need not be considered here. The engineering difficulties are in themselves of sufficient importance. The olution of the problem which most naturally suggests itself is the luilding of large subways, in which all the wires may be placed, as well as the water and other pipes, pneumatic tubes and other modern appliances; the subways to be of a size admitting men to enter at convenient points for placing and repairing the wires and pipes without interfering with the street traffic. The cost of such subways would be so great as to forbid their construction except to a limited extent.

On the other hand, the use of small conduits or tubes, into which the wires shall be drawn through numerous openings in the street surface, will necessitate almost constant interference with traffic, and frequent disturbance of the pavement of the streets and sidewalks for enlargements and repairs, and for making connection with buildings.

I am inclined to think that what may be designated as the mixed system would be the most satisfactory, under which large subways would be used on streets where the number of electric conductors and of pipe lines required for all purposes was sufficient to warrant the xpenditures for such structures, while for the other streets a system of erial carriage and distribution might be devised which would be free rom the gravest objections to the present practice, and which would lmit of gradual expansion without interrupting traffic until the roper time for the construction of a subway had arrived.

Before dismissing the subject of municipal engineering, I desire to y a few words in regard to the difficulties which are in the way of a oper management of the engineer department of our cities and the

means of removing them; not specially for the benefit of the profession, but of the community at large. The greatest obstacle to the proper conduct of public work in cities and villages arises from the fact that the engineer is frequently selected from political preferences, which often gives the position to an incompetent man. Another obstacle is that the term of office is generally limited by law to one or two years, which does not allow enough time for even a competent engineer to become thoroughly acquainted with his duties, and with the distinctive features and requirements of the locality, before he is liable to be displaced. If the evils arising from such a state of affairs are to be avoided, appointments should be based on strict civil service principles. No person should be appointed on any other ground than that of competency and honesty, and he should hold his office during good behavior; and all subordinates should be selected on the same principles.

Some of our large cities, recognizing the evil effects of political appointments of officers in charge of public works, and of frequent changes, have tried to remedy these by placing the general government in the hands of boards of commissioners, generally selected from among prominent business men in the community. Changes of this kind have usually been made when a reform wind was blowing, it being supposed that, although changes in the members of these boards might take place, the intelligence of such a class of men would be a guarantee against causeless changes of employees. This system, while it has been an improvement on the old one, has the disadvantage that members of these boards are too often hardly more than figure-heads, whose duties might just as well be performed by the engineers entrusted with the planning and execution of the public works. To make a board of public works thoroughly useful, the majority of the members should be engineers, each of whom should take charge of a particular department as its chief. By this system the board would have the benefit of the special information of each member as regards his own department, as well as of his general knowledge of engineering matters. St. Louis, Providence and Milwaukee have partially adopted this system, and it is to be hoped that other cities will follow their example.

In connection with this subject, I am pleased to record the fact that in some cities positions on public works are now made dependent on the result of examinations held under civil service rules.

Next in importance to municipal engineering, I consider the work of the railroad engineer.

During 1885 about 3 000 miles of railroad were constructed in the United States. This is less than for any one year since 1878; yet there seems now to be some revival in railroad construction, as from January 1st to June 1st, 1886, 1 100 miles of railroad have been constructed, as against 600 miles during the corresponding period of 1885.

The total mileage of railways in the United States may now be taken as about 129 500 miles.

The rapid increase of railroad traffic, and the introduction of freight cars carrying as much as 60 000 pounds, has directed the attention of railroad managers to the necessity for the improvement of brakes for freight trains.

In a paper read before our Society, it has been stated that the number of freight cars in the United States provided with power brakes on June 1st, 1885, probably did not exceed 4 per cent. of the total number. In June, 1885, the Master Car Builders' Association instituted a series of experiments, with a view of determining the merits of different brakes proposed for freight service. Another set of experiments upon automatic brakes is to be made under the auspices of the same Association, at Burlington, Ia., on July 13th, 1886, in which the best brakes now in use will be brought into competition. The results of such competitive tests will be of great value to railroad interests.

Of the various devices used for increasing the safety of railroad operations, one of the most effective and important is the block signal system, almost universally used in England, and which it is to be hoped will before long find general application in our own country.

A great obstacle to improvement in railroad transportation arises from the great variety of designs prevailing in the rolling stock and other appurtenances of railroads, and it would contribute greatly to safety and economy if uniformity in these respects could be attained.

If all, or a considerable number of railroad companies would combine to establish, at common expense, a station where experiments and tests as to the value of railroad plant, rolling stock, and appliances could be made on a large scale, and under the direction of scientific and practical men, it would save them the expense of individual efforts, and secure much more trustworthy results.

As an instance in which the railroad companies have perceived the

benefits arising from uniformity, I may mention the change of gauge from 5 feet to the standard, lately made on the Southern roads. Between May 31st and June 3d of this year the gauge on 11 500 miles of road was changed with perfect success, and with hardly any interruption of traffic.

A great advance in the construction of mountain roads has been made by Abt, whose system has been successfully applied on the Hartz Railway.

Ship railways have heretofore been used for transporting small vessels, but it was reserved for a Member of this Society to work out the details of the problem of applying railroads to the transportation of the largest sea-going vessels long distances overland in a manner which is fully indorsed by a number of the most eminent engineers and naval constructors.

The construction of the Chignecto Ship Railroad from the Gulf of St. Lawrence to the Bay of Fundy, similar in its details to those proposed for Tehuantepec, is now under contract, and the project of a ship railroad across the Peninsula of Florida is being discussed.

The system of elevated railways is remarkably successful in the City of New York, and is being extended to the suburban districts north of the city. There are also similar lines in operation, or in progress of construction, in Brooklyn and Kansas City.

Cable tramways were first used in San Francisco in the year 1873; in New Zealand, 1880; Chicago, 1882; London, England, 1884; Melbourne, Philadelphia, and Kansas City, in 1885; and during the present year in New York and St. Louis. For short lines this system has many advantages, but for long lines the use of some other motor will probably be found more economical.

Electricity has for several years been in use for operating city and suburban tramways. There are different methods of carrying the electric current from the central station to the cars. In almost every case a separate conductor is used, either overground, as at Berlin, Baltimore, and the Giant's Causeway, or in slotted conduits similar to those used on cable tramways, but of smaller dimensions, as at Cleveland and on the Blackpool line. Electric tramways have been tested during the year, or are now in process of construction, at Toronto, Can.; New Orleans, La.; Minneapolis, Minn.; Detroit, Mich.; Montgomery, Ala.; Denver, Colo.; and Appleton, Wis.

Different from these systems is that of Reckenzaun, who carries the electricity for operating the motor along with the car in a storage battery. This system is now being tried at Battersea, England. If storage batteries can be constructed which, besides being light and durable, will return a fair percentage of the power used in charging them, this system would give promise of great economy and convenience.

The rapid development of the application of electricity to many of the necessities and comforts of civilized life, would seem to demand that more attention than heretofore should, by the profession at large, be paid to this branch of engineering. A knowledge of this science will within a few years be just as necessary to the civil engineer as is to-day the knowledge of hydraulics.

The building of inland canals has on this continent nearly ceased, as railroad transportation, although more expensive, insures greater regularity and dispatch, and is not subject to stoppage during winter as are our Northern canals. Canal work is now almost entirely confined to deepening and widening the existing lines. The Welland and the Erie Canals are being thus treated. The locks of the Sault St. Marie Canal have been deepened so as to admit vessels of 10 feet draught.

But while the construction of inland canals is now at a standstill, a number of ship canals are in progress or projected. The most important of these, the Panama Canal, is, according to latest advices, not making such progress as to satisfy the friends of the enterprise. Indeed it would appear that, if completed at all, it may have to be changed into a canal with locks.

The canal across the Isthmus of Corinth is in progress.

Among projects for ship canals, which are reasonably certain of being carried out in the near future, is the canal between the Baltic and the North Sea, and the Manchester Canal in England. Canals are also proposed from the Baltic to the White Sea *via* Lake Onega, and across the Isthmus of Nicaragua.

These engineering works, if completed, cannot fail to exercise a very beneficial influence on the commerce of the world.

The subject of irrigation is of the utmost importance to some of our States and Territories, and a large amount of this class of engineer-

ing work has been done in California, Arizona, Colorado, Dakota, Montana, Idaho, Oregon and Georgia. The total length of ditches, pipes and flumes is estimated at over 10 000 miles. The greatest progress in regulating the collection and distribution of water for purposes of irrigation has been made in Colorado, and the wise laws enacted by that State are considered and used as models by other States.

From the excellent report of the State Engineer of Colorado, it appears that there are over twenty-six water districts in existence in the State, distributing over 1 800 000 cubic feet of water per minute for purposes of irrigation. The number of acres irrigated in this State exceeds 1 400 000. An irrigating canal, 30 miles in length, is now under construction at Catlin, Colorado.

The extent and cost of some irrigating works is shown by the canal in San Joaquin Valley in Merced County, California. This canal is about half completed, and will, when finished, have a total length of 35 miles. It will pass through two tunnels, one 1 600 feet, the other 6 000 feet in length. The total cost of the work is expected to be $1 500 000.

A still larger irrigating canal is being excavated in Northern Wyoming, and will be more than 100 miles in length.

The improvement of our rivers, and more particularly of the Mississippi River, in which one-third of the population of the United States is directly interested, has made but little progress during the past year, owing to the failure of Congress to make the necessary appropriations. A costly plant of steamboats, barges, pile-drivers, etc., has been prepared for the prosecution of this work. Not only does all this plant remain unused, but the works already begun, which avowedly had been constructed rather light for the purpose they were intended to serve, are gradually giving way under the attacks of the river, and before long, if not cared for, will altogether disappear. This making appropriations sufficient to start work one year, and refusing next year even the money necessary to secure and complete what has already been commenced, is certainly the height of folly, and it is to be hoped that Congress, when arriving at a full understanding of the effects of such action, will not hesitate to change it. The completion of the Davis Island Dam on the Ohio River during the year marks a very decided forward step in the improvement of that river.

The storage reservoirs which have been constructed on the Missis-

sippi River, 300 to 500 miles above St. Paul, with a view to regulating the flow of water in the river, were opened on the 1st of August, 1885, and have so far fulfilled all reasonable expectations as to their effect, and it is probable that these results, achieved with a comparatively small outlay of money, will encourage the authorities to further steps in this direction.

In the field of military engineering complete success has crowned Gruson's efforts to construct shields and cupolas of chilled cast-iron. Experiments have been prosecuted in torpedo construction and service, and also in the firing of shells filled with nitro-glycerine, which are said to have been successful. In addition to the foregoing, the Maxim machine gun, operated by the recoil, is a very important recent invention in gunnery.

It is greatly to be hoped that Congress will before long see the necessity of providing for our sea-coast defenses. When this is done, the present number in the Corps of Engineers of the United States Army would hardly suffice to plan and construct these works, and they would then be fully employed in the sphere of military engineering proper, leaving the improvement of rivers and harbors, and of all works of a civil character, to civil engineers. This would be the most natural and easy solution of the question now under discussion between members of the profession as to the proper policy of conducting public works. While it is my opinion that public works of a civil character could as well be carried on by civil engineers, appointed under strict application of civil service rules specially adapted to the purpose, I am opposed to any action by our Society which might seem to be directed against the interests, or even privileges, of a number of our Members, who are second to none in scientific attainments, in experience, and in character.

Tunneling nowadays can be done much more expeditiously and cheaply than formerly, in consequence of the improvement in drills and in explosives, coupled with better methods of ventilation.

Of large tunnels recently opened to traffic, may be named those of the Severn and the Mersey.

The construction of the Cascade tunnel on the line of the Northern Pacific Railway has been commenced. It will be 9 850 feet in length, and next to the Hoosac, the longest railroad tunnel in America.

Projects are on foot for several new Alpine tunnels; among them a tunnel under Mont Blanc, to be 12 miles in length, and one under the Simplon, to be 12½ miles long. But a prediction has been made, based on the experience gained in other Alpine tunnels, that the heat in the central portion of the Simplon tunnel would prove so great as to make human life impossible.

A project for a tunnel under Northumberland Straits, between Capes Traverse and Tormantine, deserves to be mentioned, as it proposes some bold and novel features of construction, and yet seems to be well considered in all its details, and to give fair promise of success.

The project of a tunnel under the Straits of Dover, according to late information, has a fair prospect of being revived. It is very desirable that a work which will confer such great benefits on the two countries which it is to unite should be completed; particularly since the work already done has made it a certainty not only that the construction of the tunnel is practicable, but that it can be completed in a shorter time and for less money than was originally estimated.

By far the largest work of subaqueous tunneling for the purpose of removing rock impeding navigation, was that of Flood Rock in Hell Gate. The area over which the work extended comprised nine acres. By the final explosion of October 10th, 1885 (in which 225 000 pounds of rackarock and 75 000 pounds of dynamite were used), a quantity of rock estimated at 200 000 cubic yards was shattered so as to admit of ready removal by dredging.

The greatest activity in any branch of civil engineering during the past year seems to have prevailed in bridge construction. Quite a number of important bridges have been completed, among them that across the Susquehanna River, on the Baltimore and Ohio Railroad, 6 315 feet in length, having four spans of 480 feet, and one of 520 feet; the Henderson Bridge across the Ohio River, 3 200 feet in length, with one span of 525 feet; the St. John's River Cantilever, 447 feet between piers; and the bridge across the Big Black River. Of large bridges in course of construction, the most important are the Forth Bridge, with two spans of 1 700 feet each; the Sukkur Bridge, across the Indus, having a span of 790 feet; and the Lachine Bridge, on the Canadian Pacific Railroad, with two spans of 408 feet.

The contract for the erection of a bridge at Hawkesbury, New South

Wales, has lately been awarded to one of our American Bridge Companies, a very gratifying fact when it is considered that the contract was obtained in competition with various bridge companies of England and France. The main difficulty to be overcome in the construction of this bridge lies in its deep foundations, which are to be sunk to a depth of 170 feet below the surface of the water.

The extremely low price of iron and steel greatly favors the selection of long spans for bridges, as the saving in piers and foundations balances the extra cost per lineal foot of long spans.

The tendency among bridge engineers at present seems to be favorable to the selection of systems in which the strains to which any member may be subjected can be accurately determined by calculation; and the use of the pin joint, which may be called a distinctive feature of American bridge construction, favors the attainment of this object. The rapidity with which bridges with pin joints can be erected is an immense advantage, particularly when material for such bridges has to be prepared at a great distance from its final destination, or when erection must take place where no facilities for doing iron-work exist. This system of construction is therefore particularly adapted for new and thinly settled countries.

Since the great success of the cantilever bridge at Niagara Falls, a number of other bridges have been built on this principle. Indeed by far the greater number of long span bridges lately proposed are to be cantilevers, as this system offers great advantages in erection. But they are subject to greater deflections than those built on other systems, and I believe that the arch might, in many cases, be preferable, as it gives almost the same facilities in erection, and is less deflected under the action of a moving load. I am glad to see the arch proposed in a late design for the Harlem River Bridge.

As I have before mentioned, both the weight of locomotives and of cars has greatly increased of late, and bridges constructed years ago, of sufficient strength to carry the load which at the time of their erection was considered a possible maximum, are now, by the increase in the weight of rolling stock, subjected to loads which greatly reduce their factors of safety. There are undoubtedly a great many of the older bridges which require to be strengthened or replaced if accidents are to be avoided.

I think it is the duty of the members of the profession to direct the

attention of State governments to this fact, and to suggest that thorough examination of all bridges be made. This would be a work of considerable magnitude, and would require both time and money, but in a civilized commonwealth the care for the safety of the citizens should outweigh any financial considerations.

The necessity of tests and experiments when new forms or new materials are to be introduced, will be readily admitted. To make such tests, not on small models, as at one time was considered sufficient, but on full-sized members, as has been shown to be preferable, requires large testing machines and plenty of both time and money. No individual engineer, and but few corporations, can afford to provide the necessary funds for this purpose. It was therefore proper, that for the advancement of science, as well as for the benefit of the material interests of the whole country, the United States Government should cause a testing machine of large dimensions to be built, which, under proper regulations, would be accessible to engineers and manufacturers for tests of material.

Such a machine was erected at Watertown, Mass., has been in use for several years, and has proved of very great service; yet, being under the immediate control of the Ordnance Department of the United States Army, it is, during a great portion of the time, necessarily employed in the service of that Department, and as a great many of the specimens tested are of small dimensions, the experiments made thereon are not of any value to the general public, and the primary object for which the construction of this machine was undertaken is partly defeated. A remedy would be found if the United States Government could be induced to erect, in addition to this large testing machine, some machines of smaller dimensions, and at the same time to appropriate an amount sufficient to pay for tests, not of special, but of general, interest, and for the time of engineers specially charged with the work.

While on the subject of tests, I may mention that during the past year there have been made public the results of a number of valuable experiments made by Members of this Society on cements; on the comparative value of lubricants; on evaporation; on the strength, elasticity, etc., of iron and steel; and on other matters of interest to the profession.

The use of the new system of notation of time is gradually extending,

and promises to become universal in application. The introduction of the metric system is also progressing, though not quite so rapidly as might have been expected from the progressive spirit of our nation. It seems strange that in this age of rapid interchange of goods and thoughts between civilized nations, such an obstacle as the use of different measures in different parts of the globe should be allowed to exist. Nobody can doubt that this obstacle will be removed before long, and the only question can be, what system should be adopted.

There are now 242 000 000 of people using the metric system, and the weight of numbers is probably already on the side of that system. This may be balanced, or even outweighed, by the industrial prominence of the nations which use the English standard; but the selection should clearly not be made either on the basis of the greater number now using a particular system, nor on the cost of the change in money, or in temporary inconvenience, but it should be made on the intrinsic merits of the system. And there can be no doubt that the metric system fulfills almost every condition of a perfect system of measurement, and could hardly be improved.

Among the strong objections to the introduction of the metric system, has been the necessity which it involves of a partial remodeling of the tools in our workshops. This would undoubtedly be very serious, but the saving in time to all classes who are engaged in any kind of business requiring measurement and calculation (and there are but few which do not require them) would soon make up for this loss. As to the inconvenience resulting from its introduction in the ordinary walks of life, it will, judging from the experience of Germany, hardly be felt in a country in which education is so universally distributed and the mental activity of the people so strongly developed as in our own. But even our manufacturers may be willing to agree to the change when they consider that many countries showing rapid progress, such as Brazil, Mexico and the Republics of South America, have adopted the metric system, and that this gives to France and Germany a great advantage over the United States in selling to these countries their manufactures.

I am glad to be able to state that a bill has been introduced in Congress which prescribes that, after the 4th day of March, 1892, the metric system shall be exclusively used in all transactions in which the Federal Government is concerned.

I may congratulate you upon the rapid growth of the Society, both in numbers and influence, but it is yet far behind the Institution of Civil Engineers of England as to numbers, and probably even more so as regards influence. This is mainly due to the fact that English capital has been largely employed in the English colonies, and in foreign countries, in enterprises managed by English engineers; while our capital and the services of our own engineers were, until lately, almost exclusively needed at home; and to the further fact that the English people hold the profession which produced some of their greatest men, such as Watt, Smeaton and Stephenson, in higher esteem than has been the wont of our own fellow countrymen.

But our country is getting both richer and wiser every day, and I hope the time is near at hand when American engineers will attain a wider sphere of action and a higher degree of public esteem. Those of us who have seen engineering, as a profession, start into life in the United States, may not see that hope realized, but we have the satisfaction of knowing that we have earnestly striven for the attainment of this end.

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ON THE STRENGTH OF COLUMNS: DISCUSSING THE EXPERIMENTS WHICH HAVE BEEN ACCUMULATED, AND PROPOSING NEW FORMULAS.

By THOMAS H. JOHNSON, M. Am. Soc. C. E.

READ AT THE ANNUAL CONVENTION, JUNE 26TH, 1885.

The history of the efforts made in the past fifty years to ascertain the law governing the strength of long columns is well known to the profession; nevertheless a brief *résumé* of the efforts made in this direction will not be out of place at this time.

In nearly all other forms in which the materials of construction are used, the relations between force and resistance can be readily deduced by analytical methods; but in the case of columns, that method of investigation has not proved satisfactory. Euler gave us a formula for the flexure of very long columns, obtained from the equation of the elastic line, but this did not meet the wants of the engineer for the cases arising in ordinary practice, and we have been compelled to resort to empirical methods of solving the problem.

Passing over the earlier experiments of Tredgold, Barlow, Rondelet and others on the strength of wood, which, because of its cheapness, made a rigid adherence to exact proportions less imperative, we come to the period, about 1830 to 1840, when iron began to attain greater prominence as a building material. The higher price of this material made it important that engineers should deal more exactly with the problem, so that while building safely, they might not build wastefully.

The well-known experiments made by Mr. Eaton Hodgkinson in connection with the building of the Conway and Britannia Bridges, have been made the basis of all the formulas that have been proposed, the methods of obtaining the formulas being in all cases purely empirical. Mr. Hodgkinson himself was unable to obtain a *single* formula that would agree with the whole series of experiments throughout all length ratios. He established certain limits, and gave to the profession two separate formulas. And further, he found it necessary to fix the limit differently as applied to square and round-end columns. His formulas served a very useful purpose, although they were crude in form and difficult of application.

Mr. Gordon, taking the same series of experiments, and proceeding on the assumption that a column to support a given load requires a certain area to resist the direct compression, plus a certain additional area to resist the tendency to flexure, succeeded in obtaining a formula that would meet, reasonably well, the whole series of experiments. It was

$$P = \frac{f A}{1 + a \frac{l^2}{h^2}}$$

in which

$P =$ ultimate load.

$A =$ area of the section.

$f =$ modulus of compression of the material.

$l =$ length of column.

$h =$ least dimension of the section.

$a =$ a constant.

The a, as deduced from the experiments, was a compound function of the form of cross-section and the bending resistance of the column.

Prof. Rankine separated from Gordon's a that part due to the form of cross-section, by substituting for the least side of the rectangle the corresponding radius of gyration. But his a was some unknown func-

tion of the resistance to flexure, and the formula could not be applied to other materials than those embraced in the experiments (cast and wrought-iron) without other extended experiments.

The simplest forms in which force can be applied to a body are by direct tension or compression. The amount of stretching or shortening which the material undergoes is determined by the modulus of elasticity. The capacity of a material for resistance in these three respects may be called elementary moduli. Resistance to force in all other modes of application must be combinations or modifications of these. The relation which Rankine's a bore to these elementary moduli was not determined, and hence the necessity for special experiments to enable us to apply the formula to other materials.

In 1872 the Vienna *Bauzeitung* published a paper by Mr. E. Hatzel, of Bavaria, in which the author started out with the same assumption made by Gordon, that the work done by the imposed load is two-fold, viz.: direct compression, together with bending of the column; and he succeeded in establishing, analytically, a formula which is identical with Rankine's, except that he goes a step further, and determines the relation which Rankine's constant bears to the elementary moduli of the material, it being

$$a = \frac{K}{\pi^2 E}$$

When empirical and theoretical methods lead to the same result, it would seem that the evidence of the correctness of the formulas so established was complete and satisfactory. But engineers have gradually come to distrust all the formulas, and to believe either that the experiments have not been properly interpreted, or that iron has one mode of behavior in small test-pieces, and another and different one in full-sized members as used in structures. To this feeling of doubt and uncertainty we are indebted for the large number of experiments upon full-sized columns which have been made in recent years, and which form the basis of this paper.

While studying the diagrams which accompany the interesting papers on the "Strength of Iron and Steel," in the Transactions of this Society for April and August, 1884, by Mr. James Christie, M. Am. Soc. C. E., the present writer was impressed not only with the great want of conformity of the diagrams of his experiments on struts, to the curves corresponding to any of the formulas hereto-

fore in use, but also with the marked irregularity which seemed to defy all law. Believing that this irregularity was due solely to an insufficient number of experiments, so that the whole field was not fully occupied, the published results of all experiments on columns which were accessible to the writer were collated and plotted, in the hope that the different groups of experiments when thus brought together would so far supplement each other as to fill out the irregularities, and, by fixing well-defined limits to the field covered by the plotted experiments, indicate the central law governing them.

The experiments available and used, include, besides Mr. Christie's, the Cincinnati Southern; the Watertown; Mr. Hodgkinson's, both cast and wrought-iron, and such others not included in the above as could be culled from various sources. In plotting them no attempt was made to distinguish the different authorities, but the different classes of end-bearings were plotted on separate sheets. In the case of flat ends, the field of experiment proved to be sufficiently extended to indicate the law very clearly, and in the cases of other end-bearings, and of the flat-ended mild and hard steel, the conformity to this law is very plainly seen when the law is once known. No regard was paid to arithmetical averages, it being deemed safer to draw a line bisecting, as nearly as possible, the general field. The lines so drawn for the different materials and end-bearings were then carefully compared, to ascertain, if possible, their mutual relations.

In making this comparison, the following points were ascertained:

First.—That part of the line corresponding to the higher length ratios is a curve, the equation of which is Euler's formula given below.

Second.—That part of the line corresponding to the lower length ratios is a straight line tangent to the aforesaid curve, and intersecting the vertical axis at a point which is constant for each material in all the varieties of end-bearings.

Third.—The curve of Euler's equation possesses a peculiar property not heretofore noticed so far as the writer is aware, viz.: that for all tangents to the curve the ordinate at the point of tangency is one-third of that part of the vertical axis intercepted by the tangent.

Euler's formula is usually written

$$P = \frac{E a I}{l^2},$$

in which

$P =$ ultimate load supported by the column.

$E =$ modulus of elasticity of the material.

$I =$ moment of inertia of the cross-section.

$l =$ length of column.

$a =$ a constant.

For our purpose it will be more convenient to substitute for I its equivalent, $A\,r^2$, in which

$A =$ area of cross-section.

$r =$ radius of gyration of cross-section.

The equation then becomes

$$P = \frac{E\,a\,A}{\left(\frac{l}{r}\right)^2} \tag{1}$$

in which a is to be determined from the experiments.

The tangent line being a straight line, its equation must be of the general form

$$y = ax + b$$

in which a is the tangent of the angle which the line makes with the horizontal axis, and b is the distance from the origin at which the line crosses the vertical axis, which in our case $= K$. In our diagrams, y and x are respectively P and $\frac{l}{r}$.

In order to avoid confusion with the a in equation (1), we will use c instead of a in the equation of the straight line. Changing the other characters to conform to our notation, and observing that the line extends downwards to the right, and its tangent must therefore have the minus sign, the equation becomes

$$P = \left(K - c\frac{l}{r}\right)A \tag{2}$$

The property, noted above, that the ordinate at the point of tangency is one-third the ordinate at zero of abscissas, enables us to compare these two equations and obtain the relative values of a and c.

Substituting $\frac{K\,A}{3}$ for P, and transposing, equation (2), for the point of tangency becomes

$$\frac{l}{r} = \frac{2\,K}{3\,c} \tag{3}$$

and

$$\left(\frac{l}{r}\right)^2 = \frac{4}{c^2}\left(\frac{K}{3}\right)^2$$

In the same way we obtain from equation (1):

$$\left(\frac{l}{r}\right)^2 = \frac{E\,a}{\frac{1}{3}\,K}$$

and also

$$\frac{l}{r} = \sqrt{\frac{3\,E\,a}{K}} \tag{3b}$$

From either of these equations (3) or (3*b*) the length-ratio $\frac{l}{r}$ at the point of tangency can be ascertained. For greater ratios equation (1) must be used, and for smaller ratios equation (2).

From equations (3) and (3*b*), noticing that $\frac{l}{r}$ is common to both, we obtain

$$\frac{E\,a}{\frac{K}{3}} = \frac{4}{c^2}\left(\frac{K}{3}\right)^2$$

from which

$$a = \frac{4}{c^2\,E}\left(\frac{K}{3}\right)^3 \tag{4}$$

and

$$c = \sqrt{\frac{4}{a\,E}\left(\frac{K}{3}\right)^3} \tag{5}$$

With these two equations before us, we may either determine a empirically from the experimental lines and calculate the corresponding value of c; or we may reverse the process, determining c empirically and calculating a. By the latter process, which was first tried, the following values of c were obtained from the experimental lines on the diagrams:

$$c = \frac{2}{3}\sqrt{\frac{1}{E}\left(\frac{K}{3}\right)^3} \text{ for round ends} \tag{6}$$

$$c = \frac{1}{2}\sqrt{\frac{1}{E}\left(\frac{K}{3}\right)^3} \text{ for hinged ends} \tag{7}$$

$$c = \frac{2}{5}\sqrt{\frac{1}{E}\left(\frac{K}{3}\right)^3} \text{ for flat ends} \tag{8}$$

and by substituting these values of c in equation (4) the factors E and K disappear, and we obtain

For round ends, $a = 9$ (9)
" hinged " $a = 16$ (10)
" flat " $a = 25$ (11)

from which it appears that the value of a is a function of the end-bearing alone, and is entirely independent of the materials.

Navier and Weisbach both make Euler's formula.

$$P = \frac{E\,I\,\pi^2}{l^2}$$

from which $a = \pi^2 = 9.87$.

Accepting this as the correct figure for round-end columns, and determining from the experiments the values of a for other end-bearings in terms of π^2, we have

$$\text{For round ends,} \quad a = \pi^2 = 9.87 \tag{12}$$

$$\text{“ hinged “} \quad a = \tfrac{5}{3}\,\pi^2 = 16.45 \tag{13}$$

$$\text{“ flat “} \quad a = \tfrac{5}{2}\,\pi^2 = 24.67 \tag{14}$$

and from these values of a equation (5) becomes:

$$\text{For round ends } c = 0.6366\sqrt{\frac{1}{E}\left(\frac{K}{3}\right)^3} \tag{15}$$

$$\text{“ hinged “} \quad c = 0.4932\sqrt{\frac{1}{E}\left(\frac{K}{3}\right)^3} \tag{16}$$

$$\text{“ flat “} \quad c = 0.4000\sqrt{\frac{1}{E}\left(\frac{K}{3}\right)^3} \tag{17}$$

Two sets of values for a and c are therefore presented; the latter having the advantage of theoretical accuracy, at least as to round ends, while the former have the advantage of greater simplicity. The experiments agree equally well with either. For the purpose of this article the latter figures will be used, but for ordinary office requirements the simpler form is preferable.

I would also call attention to the sequence of the values of a first found; viz., 9, 16, 25. These may be written 3^2, 4^2, 5^2. Does not this adherence to the squares of the natural numbers indicate the existence of some fundamental law underlying the relations of the several forms of end resistance.

No value for fixed-end columns is given, for the reason that no experiments upon this class of end-bearings have been made. Mr. Christie, indeed, has given us a group of experiments which he has called fixed ends. In plotting they show but little departure from square ends. They all plot within the limits of the field for that class, generally above the average, but some below. Upon closer examination of the details of the arrangement for fixing the column, it appears that it consists of an enlarged square-end bearing clamped to the test piece. These experiments, therefore, have not been treated

in this paper as a separate group, but have been classed as square ends, and so plotted.

These formulas can be readily applied to any material of which E and K are known. E is the modulus of elasticity, and needs no further comment. But what is K? Comparing the diagrams, Plates Nos. XLI, XLIV and XLV, with the various characteristics of iron, mild steel and hard steel, as given by Mr. Christie on page 262 of the Transactions, August, 1884, it would appear that K is not the resistance to direct compression, but is almost identical with the transverse modulus of rupture, as determined by Mr. Christie. But, on the other hand, Plates Nos. XLVI and XLVII, for cast-iron, show that it is not that modulus, but is more nearly allied to the modulus of compression, although by no means so great as the compressive resistance shown by short prisms.

Considering that the strain producing failure is one of compression, it would seem that the modulus of compression should be the one to govern the case.

In the tabular statements of Mr. Christie's experiments, there occur a number of notes, which, taken in connection with a certain feature of the plotted results, may throw some light on the subject. Throughout those tabular statements one is struck by the frequency with which occurs the note "no failure at 50 000 pounds," and that too, even with length ratios up to and greater than 200 radii. This result is analogous to that in which water, perfectly quiescent and free from any influence to disturb the molecular equilibrium, may be reduced very much below the freezing point without the formation of ice. In those experiments to which that note is attached, the test piece must not only have been perfectly fitted at the ends and accurately centered, but the test piece must have been perfectly straight, and the material so thoroughly homogeneous, that the forces and resistances acting at each cross-section were in perfect equilibrium, so much so that an external disturbing force would be necessary to destroy that equilibrium before failure could begin.

Mr. Christie has simply been fortunate enough to obtain practical illustrations of the mathematical principle which meets one in the very beginning of an attempt to deduce a formula for the strength of columns by analytical methods. A bending moment is always the product of the applied force by its effective lever-arm. Given a straight column, with a force acting in the direction of its axis, the lever-arm is

0, hence the bending moment is 0, and conversely the sustaining power of the column (as regards flexure) is infinity. Before a bending moment can be determined mathematically, there must be a known deflection, whose ordinate is the lever arm through which the applied force acts. If the direction of the force is axial, and there be perfect equilibrium at every cross-section, there can be no deflection from which to create a bending moment. This mathematical condition was realized physically by Mr. Christie.

That "no failure" should occur at rare intervals, should not be a matter of surprise. Its frequency in Mr. Christie's work is proof both of extreme care on his part, and unusual homogeneity of his material.

But if it is possible that this condition should occur in test pieces of relatively great length, we should expect it to occur with greater frequency in experiments on the shorter lengths. Now, turning again to Plate No. XLI, we note that within the length ratios from 0 to 30 radii of gyration, the experiments whose results lie above the upper limit of the field are quite numerous. If the lower limit showed a corresponding upward course, it would indicate a variation in the law as applied to the shorter lengths. But as the lower limit maintains a continued straight course, we assume that those above the upper limit are exceptional, and they are, without doubt, due to the same causes that enabled Mr. Christie to write "no failure" so frequently.

The question naturally arises: How far has this cause operated in all experiments upon the crushing strength of materials in short prisms, and given us false values for their moduli? Is it not altogether probable that the values of K, as indicated by these diagrams, are the true moduli of the compression resistances of these materials; and that the moduli of other materials as now published and accepted are correspondingly too high?

The principle announced by Hodgkinson, and reaffirmed and extended by Mr. C. L. Strobel, M. Am. Soc. C. E., on page 104, Vol. XI, of these Transactions, that "the ultimate strength of columns under 26 to 40 diameters long, is independent of their length," is evidently not sustained when all the experiments are combined in one group; and these gentlemen were, no doubt, misled by the prevalence in the experiments before them, of a preponderance of results of the exceptional character here noted.

At and near the length ratio of 100 in plates Nos. XLI and XLII

there is also a small group of experiments whose results reach above the upper limit. These most probably indicate a tendency in individual cases to persistently adhere to Euler's law, and so follow the prolongation of the curve beyond the point of tangency. It will be seen in the formula, that of the properties of the material, the elasticity alone determines the behavior of the column in the curved portion of the field, and in the tangential portion that behavior is determined by the combined influence of the moduli of elasticity and compression, the relative influence of K being greatest when $\frac{l}{r}=0$ and diminishing to 0 at the point of tangency. It may therefore readily be supposed that near the point of tangency where the influence of K is least, it may be modified, or wholly suppressed, by accidental causes; such, for instance, as internal strain in the material, thus allowing the final result to be determined by the law of the curve instead of the law of the tangent.

The foregoing formulas and their constants were deduced from a comparison of the lines representing the average results of the several groups of experiments. If the law govering the strength of columns is correctly represented by the formulas, then by assigning to E and K their maximum and minimum values, the formulas should define the maximum and minimum limits of the field in the diagrams.

The values of E for wrought-iron are: Maximum, 38 000 000; minimum, 16 000 000; average, 27 000 000.

The values of K, as ascertain from Plates Nos. XLI, XLII and XLIII, are : Maximum, 50 000; minimum, 34 000; average, 42 000.

These maximum and minimum values applied to the formulas, give the limiting lines which have been drawn on Plates Nos. XLI, XLII and XLIII. It will be seen that a few of the experimental results lie beyond these limits. Those above the upper limit have been already accounted for, except some 6 or 8 on Plate No. XLII, hinged ends. These may have been due to some unrecorded condition of the pin-bearings giving rise to increased friction, and so making an end resistance more nearly allied to that of square ends. Those below the lower limit do not show local grouping to indicate special causes, as do the higher ones. But they can be explained by a cause which would act equally throughout all the length ratios, and one entirely consistent with the formulas and with observed results during tests. If the specimen is not properly placed

in the testing machine, the line of pressure will lie outside of the axis, and the distance between the axis of the column and the line of pressure becomes a lever arm by which the applied force is multiplied in its effect upon the column. In such cases, undetected, the recorded result would be unduly low, not because the column was weak, but because the effective force was greater than the recorded applied force. The very limited number of defective results of this class is better fitted to create confidence in the experimenters than to discredit deductions made from their work.

Having obtained the foregoing formulas from the published experiments on wrought-iron and steel, let us see how they will conform to the experiments on other materials. In Plates XLVI and XLVII, Mr. Hodgkinson's experiments on cast-iron columns are given, for square ends and round ends respectively; and also the lines of the formulas, giving to E for cast-iron its value of 16 000 000. The value of K for cast-iron, indicated by those experiments, is 80 000 (75 per cent. of the modulus of compression), and the resulting lines agree with the experiments.

Plate No. XLVIII shows some experiments on seasoned oak made by Lamande. They are taken from "Appleton's Dictionary of Engineering," article "Materials." Although the number and range of these experiments is quite limited, their harmony with the formula is very satisfactory. Here $K = 5\ 400$, which is also about 75 per cent. of the modulus of compression.

It is a matter of regret that the extended series of experiments made some years since by Mr. C. Shaler Smith, M. Am. Soc. C. E., upon white and yellow pine have never been published. They would have afforded a valuable check upon these formulas, besides contributing largely to our general knowledge of these materials which are in daily use.

Perhaps the most extreme test of the formulas would be their application to building stones, whose physical properties present a greater contrast to those of iron and steel than is afforded by any other building material. The writer hopes at no distant day to lay before this Society a series of tests upon long prisms of oolitic limestone of Indiana, this stone being selected for the reason that its moduli have been fully determined, and are as follows:

Modulus of compression	12 600
" elasticity	4 350 000

Modulus of rupture (transverse).....	2 340
Value of K (probably 75 per cent. of 12 000)...	9 000

(See Indiana Geol. Rep., 1881.)

In this paper no attempt has been made to trace the influence of the details of construction, relative size of pins to columns, limiting thickness of thinnest plates, etc., the aim having been to investigate only the general law. Judging from the fact that nearly all the experiments heretofore made are included within the limits due to the extreme variations in the quality of the material, it would seem that the other conditions enumerated are of secondary importance, and belong to that class of refinements of theory which cannot be utilized in practice, because they are dominated and obscured by the variations in the material. This statement must be taken, however, with the proviso that in all riveted work the pitch must be so proportioned to the thickness of plates that the strength per square inch of the plates between rivets shall not be less than the strength of the column considered as a whole.

Before closing this article, it will be well to revert to the older formulas and the reasons why they fail to give satisfactory results. It is apparent from the Plates, especially Nos. XLI and XLII, that Hodgkinson's experiments were too few in number to lead to correct results. Gordon fell into error, not only from the paucity of experiments at his command, but also by following Tredgold's assumption that a certain portion of the area is required to resist flexure. Under this assumption the modulus of compression would remain as a factor in the equation for all length ratios, but with diminishing influence, becoming zero only when $\frac{l}{r}$ becomes infinite; whereas it now appears that the modulus of compression ceases to be a factor when $P = \frac{K}{3}$. Hatzel following in the footsteps of Tredgold and Gordon was also led to equally erroneous results.

With the present formulas the construction of a diagram is very simple. A sufficient number of points having been calculated to plot the curves, a tangent line can be readily drawn to the point representing the value of K. All the experiments on steel indicate that a common value of E (27 000 000) will apply for wrought-iron and for all grades of steel. Hence, having constructed a diagram for wrought-iron, any grade of steel may be represented on it by drawing the tangent line to the point representing the proper value of K. A series of experiments to determine

the relation existing between the value of K and the percentage of carbon might lead to interesting and useful results.

Plate No. XLIX illustrates the relations between wrought-iron, mild steel and hard steel (carbon = 0.12 and 0.36 respectively) when used as flat-ended columns; the metal being assumed to have a uniform value of $E = 27\ 000\ 000$ pounds for all grades. On page 264 of the Transactions for 1884, Mr. Christie points out, as one result of his experiments, the practical equality of the resistance of these three metals for the higher length ratios. This diagram shows that the formulas herein presented fully recognize that fact.

Inasmuch as all experiments upon both large and small sections are here grouped together, and show no differences except those due to ordinary variations in the material, it is evident that a common law governs all the sizes tested, and we may return to the smaller and less costly test pieces with ample assurance that if only they are sufficient in number, the result will be equally valuable with those obtained from full-sized members.

The foregoing general formulas, with special values for different materials and end-bearings reduced to the simplest form, are appended in tabular form. The formulas for mild and hard steel, as given in the table, will be found to differ from the corresponding diagrams in the value assumed for E. The object of the diagrams being to aid in establishing the formulas, E was taken at 30 000 000 as most nearly representing the quality of the metal used in the experiments. (See Mr. Christie's papers). On the other hand the formulas in the tables are offered for general use, and E was taken at 27 000 000, which will most probably be found to be the general average for all qualities, both of wrought-iron and steel.

Column No. 6 of the table gives the length ratio for the point of tangency; or, in other words, the limiting length for the application of the first formula. All, or nearly all, of the dimensions occurring in ordinary practice will be within these limits, and the labor of calculation will be much simplified by the new formulas.

Through the kindness of Mr. Joseph M. Wilson, M. Am. Soc. C. E., I am permitted to use two of the plates accompanying his paper on "Bridge Specifications," on which he had plotted the lines representing the different formulas that have been proposed from time to time. On these plates, Nos. L and LI, I have added the lines of the formulas

Special Forms of the Equations for Various Materials and End-Bearings.

Materials.	E.	K.	End Bearings.	For Tangent. $\frac{P}{A} = K - c\frac{l}{r}$	At P. T. $\frac{l}{r} = \sqrt{\frac{3Ea}{K}}$	For Curve. $\frac{P}{A} = \frac{Ea}{\left(\frac{l}{r}\right)^2}$
Wrought-iron.	27 000 000	42 000	Flat.	$\frac{P}{A} = 42\,000 - 128\frac{l}{r}$	218.1	$\frac{P}{A} = \frac{666\,090\,000}{\left(\frac{l}{r}\right)^2}$
			Hinged.	$\frac{P}{A} = 42\,000 - 157\frac{l}{r}$	178.1	$\frac{P}{A} = \frac{444\,150\,000}{\left(\frac{l}{r}\right)^2}$
			Round.	$\frac{P}{A} = 42\,000 - 203\frac{l}{r}$	138.0	$\frac{P}{A} = \frac{266\,490\,000}{\left(\frac{l}{r}\right)^2}$
Mild steel... (Carbon = 0.12)	27 000 000	52 500	Flat.	$\frac{P}{A} = 52\,500 - 179\frac{l}{r}$	195.1	$\frac{P}{A} = \frac{666\,090\,000}{\left(\frac{l}{r}\right)^2}$
			Hinged.	$\frac{P}{A} = 52\,500 - 220\frac{l}{r}$	159.3	$\frac{P}{A} = \frac{444\,150\,000}{\left(\frac{l}{r}\right)^2}$
			Round.	$\frac{P}{A} = 52\,500 - 284\frac{l}{r}$	123.3	$\frac{P}{A} = \frac{266\,490\,000}{\left(\frac{l}{r}\right)^2}$
Hard steel..... (Carbon = 0.36)	27 000 000	80 000	Flat.	$\frac{P}{A} = 80\,000 - 337\frac{l}{r}$	158.0	$\frac{P}{A} = \frac{666\,090\,000}{\left(\frac{l}{r}\right)^2}$
			Hinged.	$\frac{P}{A} = 80\,000 - 414\frac{l}{r}$	129.0	$\frac{P}{A} = \frac{444\,150\,000}{\left(\frac{l}{r}\right)^2}$
			Round.	$\frac{P}{A} = 80\,000 - 534\frac{l}{r}$	99.9	$\frac{P}{A} = \frac{266\,490\,000}{\left(\frac{l}{r}\right)^2}$
Cast-iron.....	16 000 000	80 000	Flat.	$\frac{P}{A} = 80\,000 - 438\frac{l}{r}$	121.6	$\frac{P}{A} = \frac{394\,720\,000}{\left(\frac{l}{r}\right)^2}$
			Hinged.	$\frac{P}{A} = 80\,000 - 537\frac{l}{r}$	99.3	$\frac{P}{A} = \frac{263\,200\,000}{\left(\frac{l}{r}\right)^2}$
			Round.	$\frac{P}{A} = 80\,000 - 693\frac{l}{r}$	77.0	$\frac{P}{A} = \frac{157\,920\,000}{\left(\frac{l}{r}\right)^2}$
Oak	1 200 000	5 400	Flat.	$\frac{P}{A} = 5\,400 - 28\frac{l}{r}$	128.1	$\frac{P}{A} = \frac{29\,604\,000}{\left(\frac{l}{r}\right)^2}$
Oolitic Limestone ..	4 350 000	9 000	Flat.	$\frac{P}{A} = 9\,000 - 32\frac{l}{r}$	189.1	$\frac{P}{A} = \frac{107\,314\,500}{\left(\frac{l}{r}\right)^2}$

herein presented, which are thus shown in comparison with the others heretofore proposed. The relations of the several lines are so clearly shown on the plates, that no special discussion of them seems to be required.

DISCUSSION.

James Christie, M. Am. Soc. C. E.—If the compressive force to which columns are subjected acted through axes whose position could be accurately predetermined, we would probably obtain more concordant results from experiment than we do, and no doubt could frame formulas, based on known physical properties of materials, which could be depended on as reliable for any length or section of column.

But, in addition to the fact that the center of stress may be acting through an axis which no care in design or manufacture can accurately foresee, we also have disturbing conditions, such as columns not perfectly straight; or, if apparently straight externally, the material at different cross-sections may be so distributed that the centers of symmetry may not coincide on any straight line.

Again, by reason of internal molecular stresses, or other unknown causes, it is questionable if the modulus of elasticity, especially for metals in compression, is uniform throughout the mass. When investigating the theory of column resistance we assume that the curve of flexure takes some regular deflection in a certain direction, whereas experiment shows that frequently several points of contra-flexure may occur in a single column, due to the sinuosity of the centers of maximum resistance. It is quite possible that this condition exists in such a large number of cases as to render it a prominent circumstance in determining the average resistance by experiment. Therefore it would seem probable that a general scale of averages derived from experiment would be a safer guide than any formula based on fundamental principles, which may be derived from theoretical assumptions which rarely obtain in practice. Having obtained a satisfactory table of average extreme resistances, it becomes the duty of the prudent engineer to adopt such working factors as will safely include the weak, erratic cases which will occasionally occur, despite ordinary care, in design and construction.

The formulas proposed by Mr. Johnson possess the merit of being fitted to a line which expresses the average resistance of known experiments. I think, however, that the value assigned to K is too small, for an examination of the diagram for flat ends of wrought-iron shows a marked number of tests of the shortest columns which lie above the maximum limit.

Assuming K to represent the modulus of compression, it might be more proper to locate the vertical axis of the diagram at some definite length instead of at zero, for the compression resistance of infinitely short specimens of a ductile metal becomes practically infinite.

I cannot understand why we should assume that the influence of K should disappear at the specific point assigned. Would it not be more reasonable to assume that the line of resistance approached nearer to the elastic curve as the column became longer, and receded further from it or approached the tangent as the column became shorter? This, however, would mar the simplicity of Mr. Johnson's formulas, and, as practical accuracy rather than a mathematical refinement is the object sought, we may accept any satisfactory formula, which, after all, can only be a compromise between so many conflicting elements.

The strength of columns within the range of lengths usual in practice, is determined more directly by resistance to crushing than by lateral stiffness. These columns are covered by Mr. Johnson's equation for the tangent, which is exceedingly simple, and admits of ready application. This observation applies more especially to metals of low tenacity. For instance, the elastic limit for compression of wrought-iron (about 29 000 pounds) will usually be exceeded in pressure before failure occurs on flat-ended columns having a ratio of l to r of 100 and under. In the same manner a soft steel having an elastic limit of 38 000 pounds will cover a range of $\frac{l}{r}$ up to 80. Hard steel of 100 000 pounds tenacity, or 60 000 pounds elastic limit, will usually cover a range of $\frac{l}{r}$ up to 60 before failure ensues from 60 000 pounds pressure per square inch.

I append herewith the results of a few tests of riveted models of iron and steel I have made recently. These specimens were each formed of two angle sections of the dimensions denoted, riveted together, side to side, forming a T-shaped section.

The holes were punched and fastened with $\frac{3}{8}$-inch rivets, 4 inches apart. Iron rivets being used on iron bars and steel rivets on steel. No care was taken to prevent the specimens being exposed to the roughest treatment usual in the operations of punching, straightening, etc. The mild steel was of 60 000 pounds tensile strength, and the hard steel 100 000 pounds.

Failure was normal in every case—that is, true flexure occurred without fracture. As the rivet holes were unduly large as compared with the sections operated upon, it is probable that the specimens were weakened more than was needful.

COMPRESSION TESTS OF FLAT-ENDED RIVETED MODELS.

KIND OF METAL.	Size of Each Angle Composing the Section.	Length in Inches.	Sectional Area in Square Inches.	Maximum Resistance in Pounds.	Maximum Resistance in Pounds per Square Inch.	$\frac{l}{r}$
	Inches.					
Iron	$1\frac{1}{2} \times 1\frac{1}{2} \times \frac{5}{16}$	$47\frac{7}{8}$	1.74	44 100	25 350	107
"	$1\frac{1}{4} \times 1\frac{1}{4} \times \frac{5}{16}$	$36\frac{1}{16}$	1.39	34 325	24 700	97
"	$1\frac{1}{8} \times 1\frac{1}{8} \times \frac{5}{16}$	$24\frac{1}{32}$	1.22	35 525	28 890	75
"	$1\frac{3}{8} \times 1\frac{3}{8} \times \frac{5}{16}$	$47\frac{23}{32}$	1.53	36 450	23 820	120
Mild steel	$1\frac{3}{8} \times 1\frac{3}{8} \times \frac{5}{16}$	48	1.54	48 425	31 757	120
"	$1\frac{1}{4} \times 1\frac{1}{4} \times \frac{5}{16}$	$36\frac{3}{16}$	1.39	44 800	32 230	98
"	$1\frac{1}{8} \times 1\frac{1}{8} \times \frac{5}{16}$	24	1.22	46 100	37 790	75
"	$1\frac{3}{8} \times 1\frac{3}{8} \times \frac{5}{16}$	$42\frac{25}{32}$	1.54	46 525	30 220	102
Hard steel	$1\frac{1}{2} \times 1\frac{1}{2} \times \frac{17}{64}$	42	1.25	48 300	38 610	93
"	$1\frac{3}{16} \times 1\frac{3}{16} \times \frac{17}{64}$	$36\frac{1}{8}$	1.18	47 650	42 165	100
"	$1\frac{5}{16} \times 1\frac{5}{16} \times \frac{17}{64}$	$48\frac{1}{8}$	1.32	46 900	35 440	130
"	$1 \times 1 \times \frac{17}{64}$	24	.95	43 575	45 750	82

I think Mr. Johnson gives insufficient credit to the group of tests of fixed-ended struts when he classes them simply as flat-ended.

The flanges attached to the ends of the specimens were as effectual in aiding resistance to lateral flexure as though they were extended over any greater area.

The general phenomena observed at the period of failure was as follows:

For lengths up to about 30 times r, the specimens failed by irregular crippling.

From 30 to about 100 times r regular curvature occurred, but the flat ends remained seated after failure. Contrary flexure was manifest near

the ends, consequently no method of securing the ends could have materially increased the resistance.

Above the latter range of length the flat-ended specimens showed a tendency to rotate on their ends at the time of failure, and in the case of the longest bars tested, the specimens tilted on their ends before the maximum resistance to flexure was recorded, and the curve became uniform from end to end. With flanges attached (fixed-ended), the ends remained rigid, no rotation whatever ensued, and the reverse curves were as apparent on the longest specimens as on the shorter free-ended bars. As $\frac{l}{r}$ exceeded 150, the resisting influence of the flanges became very apparent, below that limit this influence gradually disappeared, becoming barely discernible with $\frac{l}{r}$ at 100.

Thos. H. Johnson, M. Am. Soc. C. E.—Mr. Christie has raised a question as to the value assigned to K in my formula, and I thank him for the opportunity thus afforded of saying some things omitted or imperfectly said in the original paper.

At $\frac{l}{r} = 0$ the resistance to compression is not infinity, but must theoretically be equal to the modulus of compression.

Practically of course, experiments at $l = 0$ are impossible, and when $\frac{l}{r}$ is very small, other resistances are brought into play, so that experimenters have long since recognized the importance of making the test pieces long enough to admit of the fractured portions moving freely without added resistance. To my mind the plotted experiments show very conclusively that other causes operate which are not eliminated by making the length of test piece for compression one or one and one-half times d, as is usually done; and that these causes are not wholly eliminated, and the normal modulus of compression obtained experimentally (on metals at least) until $\frac{l}{r} = 25$, which would be for rectangular sections $l = 7\frac{1}{2}d$ nearly.

In my paper I have explained the cause operating to produce these abnormal results, and at the same time account for the many instances in which Mr. Christie failed to destroy relatively very long columns. Whether or not the explanation there offered is satisfactory, the fact remains clearly shown by the experiments, that the modulus of com-

pression as derived from short prisms is too high to be used in a formula for columns.

In case of fibrous metals, in which the resistance to tension is equal to or greater than that to compression, transverse rupture occurs by failure on the upper or compression side of the beam; and for such materials the modulus of rupture should be coincident with the modulus of compression.

Comparing the moduli of rupture given by Mr. Christie on page 262 of Volume XIII of the Transactions of this Society with the values of K obtained from the diagrams, we have the following:

	Iron.	Mild Steel.	Hard Steel.
Modulus of rupture.....	44 800	52 900	80 200
Value of K.....	42 000	52 500	80 000

For materials which do not fail by compression at the upper side, the modulus of rupture is usually a compound function of the moduli of tension and compression, so that the results of transverse experiments cannot be compared with the values of K as used in the formulas.

Hodgkinson gives the modulus of compression for the cast-iron used by him in his experiments at 109 800 pounds. The diagram shows that the value of K which best conforms to his experiments is 80 000 pounds, which is 73 per cent. of the modulus obtained from short prisms.

The modulus of compression for oak is about 7 500 pounds, and the value of K from the diagram is 5 400 pounds, which is also 73 per cent. of the modulus obtained from short prisms. I have therefore assumed (provisionally) that in applying the formulas to materials in which experiments on long columns are wanting, it will be proper to assume the value of K at about 75 per cent. of the modulus of compression as obtained from short prisms.

Returning to the specific point made by Mr. Christie, that the value of K taken by me is too low, as evidenced by the diagram for flat ends, I would call attention to the fact that the value of K is a property of the material entirely independent of the end resistance, and must apply alike to all forms of end bearings. In fixing its value from the diagrams,

all of the forms of end bearings must be kept in view, and such value taken as will best fit all of them. This I endeavored to do. The figures given by me will bear modification, within certain limits, without greatly disagreeing with the experiments on the several forms of end bearings; but they appear to harmonize all the forms of end bearings to the best advantage.

In treating the fixed-end experiments as flat ends, I did not mean to assert that the flanged ends had no effect. They do show results somewhat higher than the average of the flat ends, but it seemed to me that the difference would not warrant a separate discussion of them; besides, the number of experiments was quite limited, especially in the curved part of the field.

The equation of the tangent for this group of experiments would be

$$\frac{P}{A} = 42\,000 - 123\,\frac{l}{r} \tag{a}$$

and for the curve,

$$\frac{P}{A} = \frac{27\,Ea}{\left(\frac{l}{r}\right)^2} \tag{b}$$

The point of tangency will occur at $\frac{l}{r} = 228$.

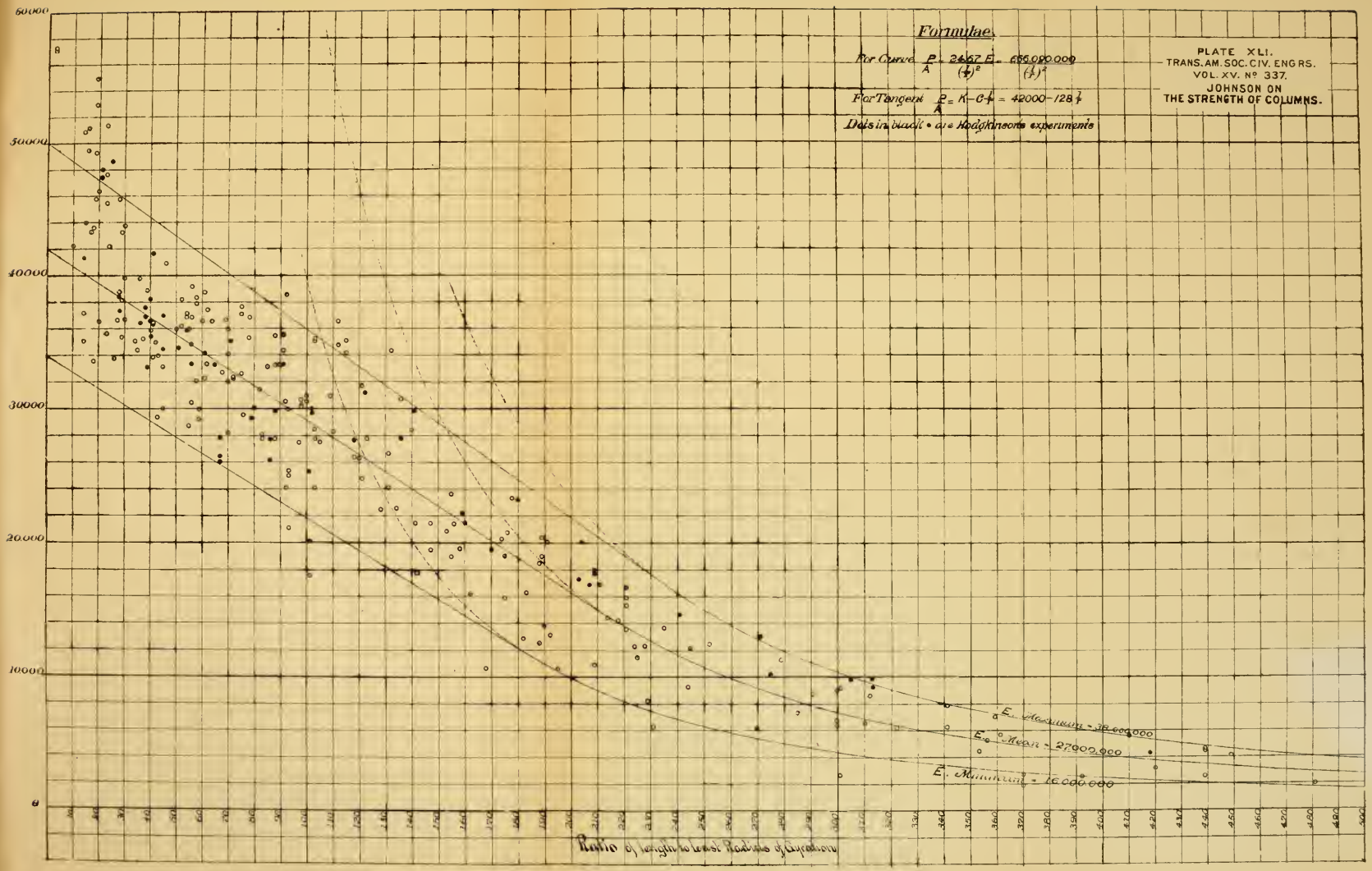
Eq. (b) will give results only about 8 per cent. higher than the equation for flat ends for length ratios greater than 228. For smaller ratios the percentage of gain diminishes in proportion to the length ratio.

Inasmuch as flanged columns are seldom used in engineering works, though more frequently in architectural structures, it would appear to be judicious to disregard the slight increase of strength due to the flange, and treat all such cases as square ends.

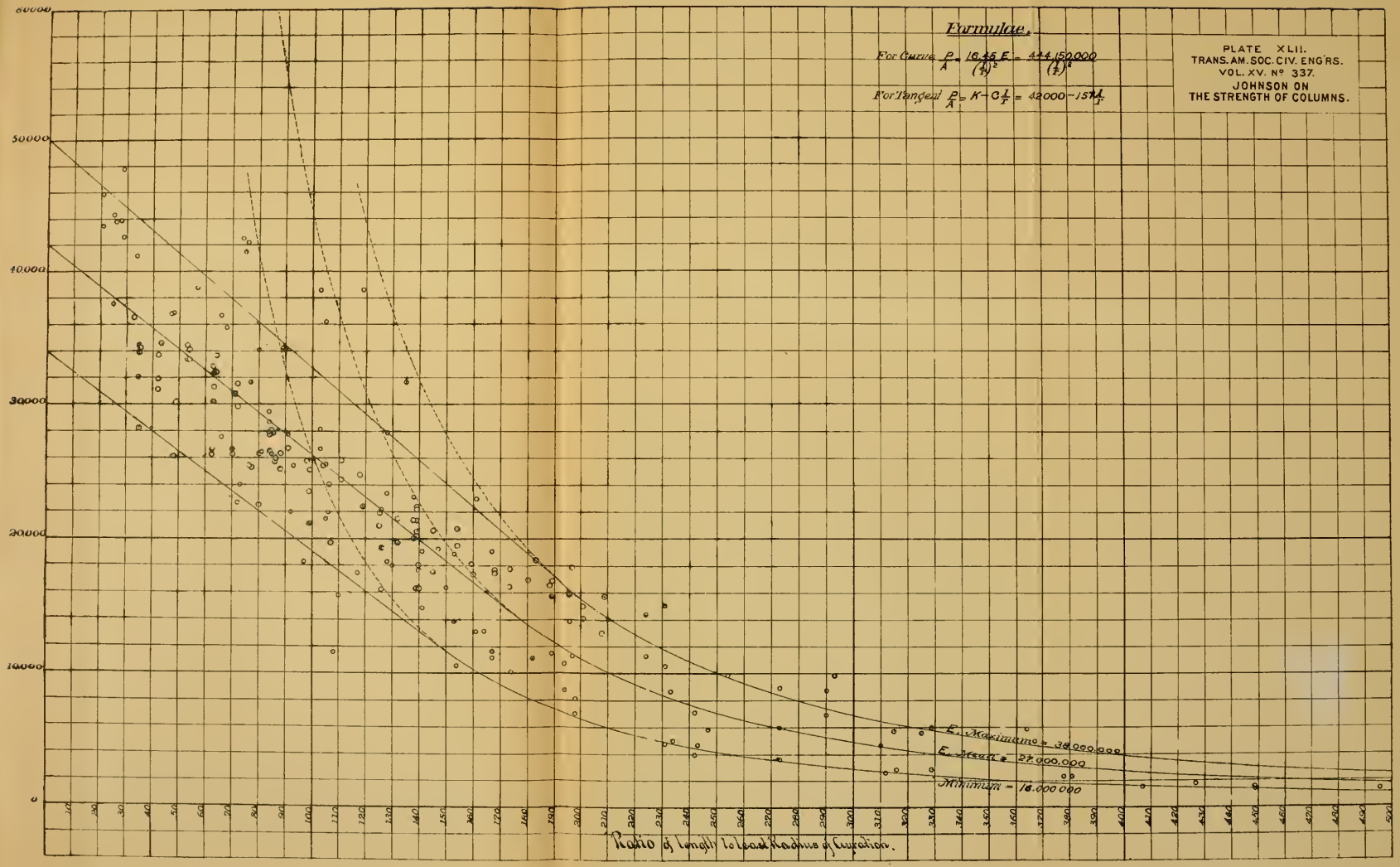
Euler's equation is a theoretical deduction made years ago, and the experiments prove that it is correct for the higher length ratios. The resistance to crushing is not a factor in that equation, and hence its influence must become zero at the point where that equation begins to apply. Why this should be so is difficult to see in the light of our present knowledge; but the evidence goes to show that it is a fact.

WROUGHT IRON

FLAT ENDS.

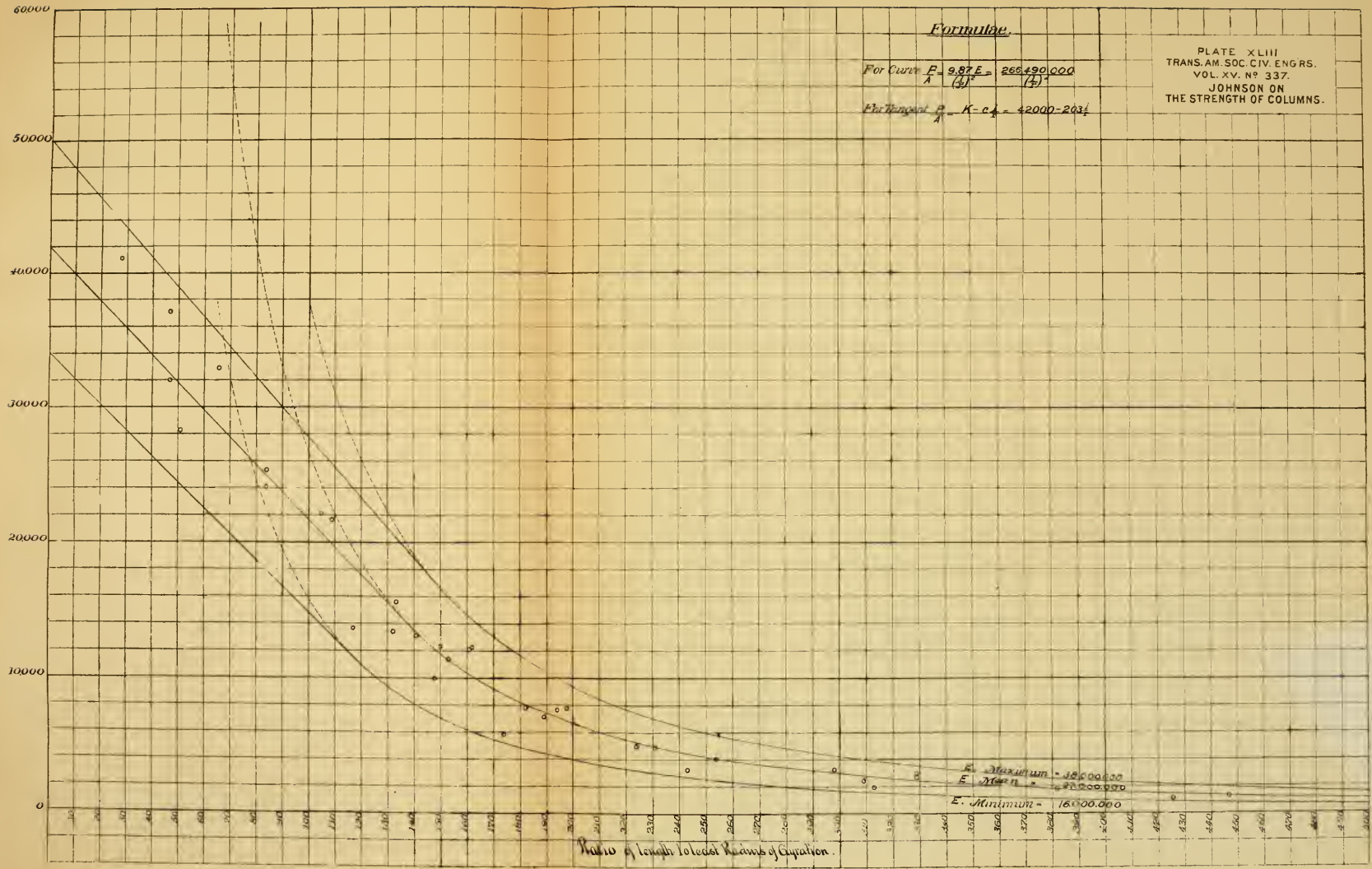


WROUGHT IRON. **HINGED ENDS.**



WROUGHT IRON.

ROUND ENDS



MILD STEEL.

FLAT ENDS

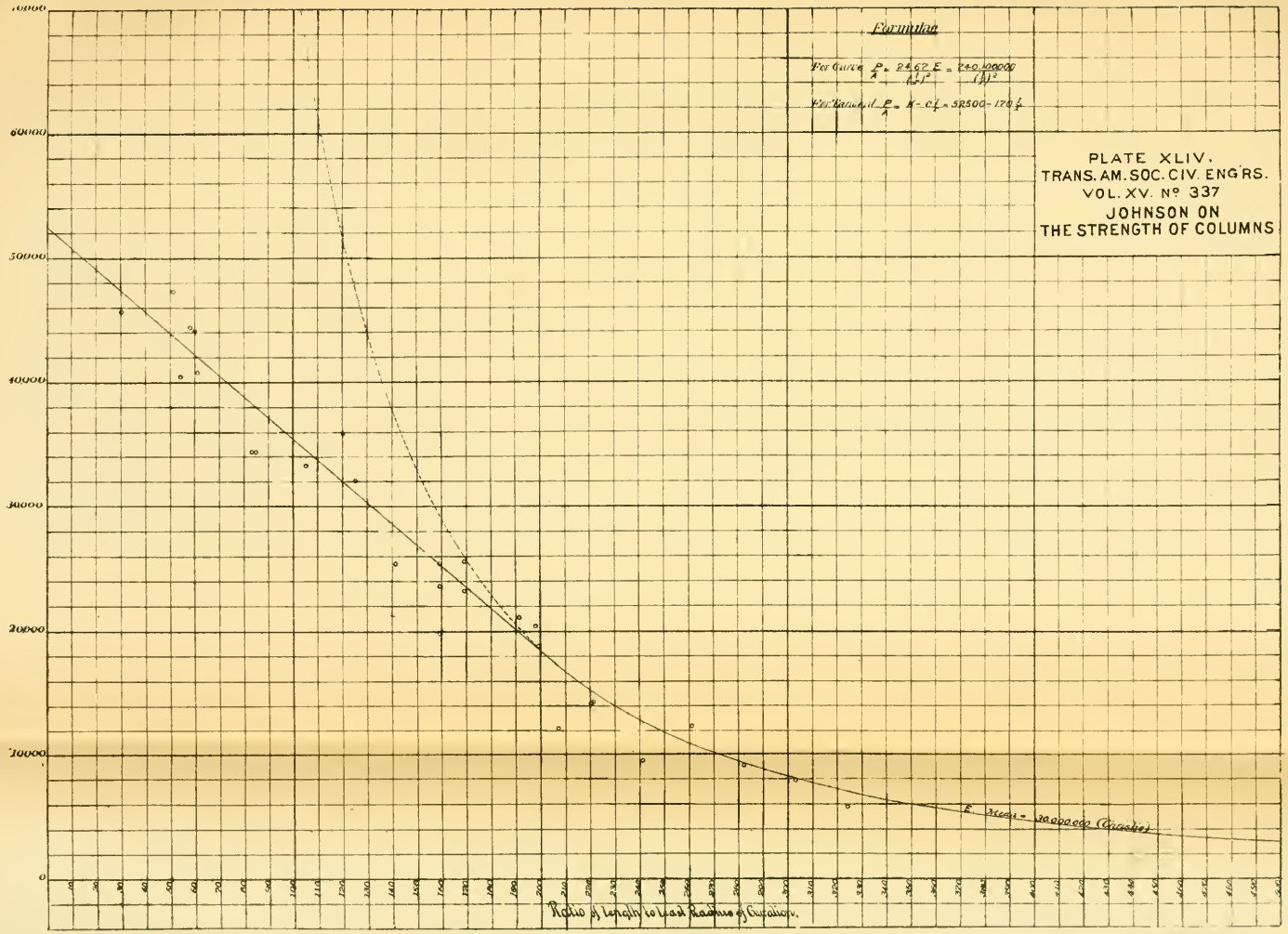


PLATE XLIV.
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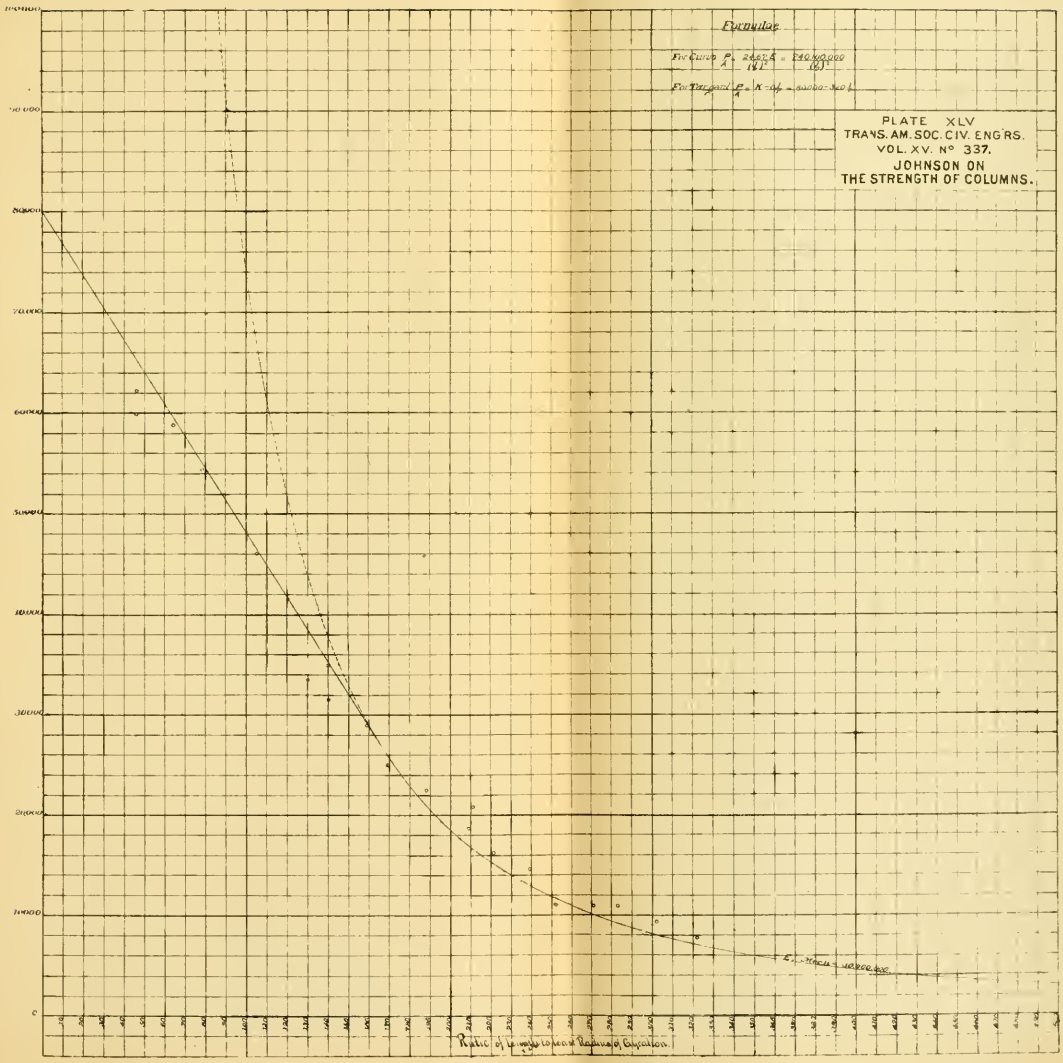
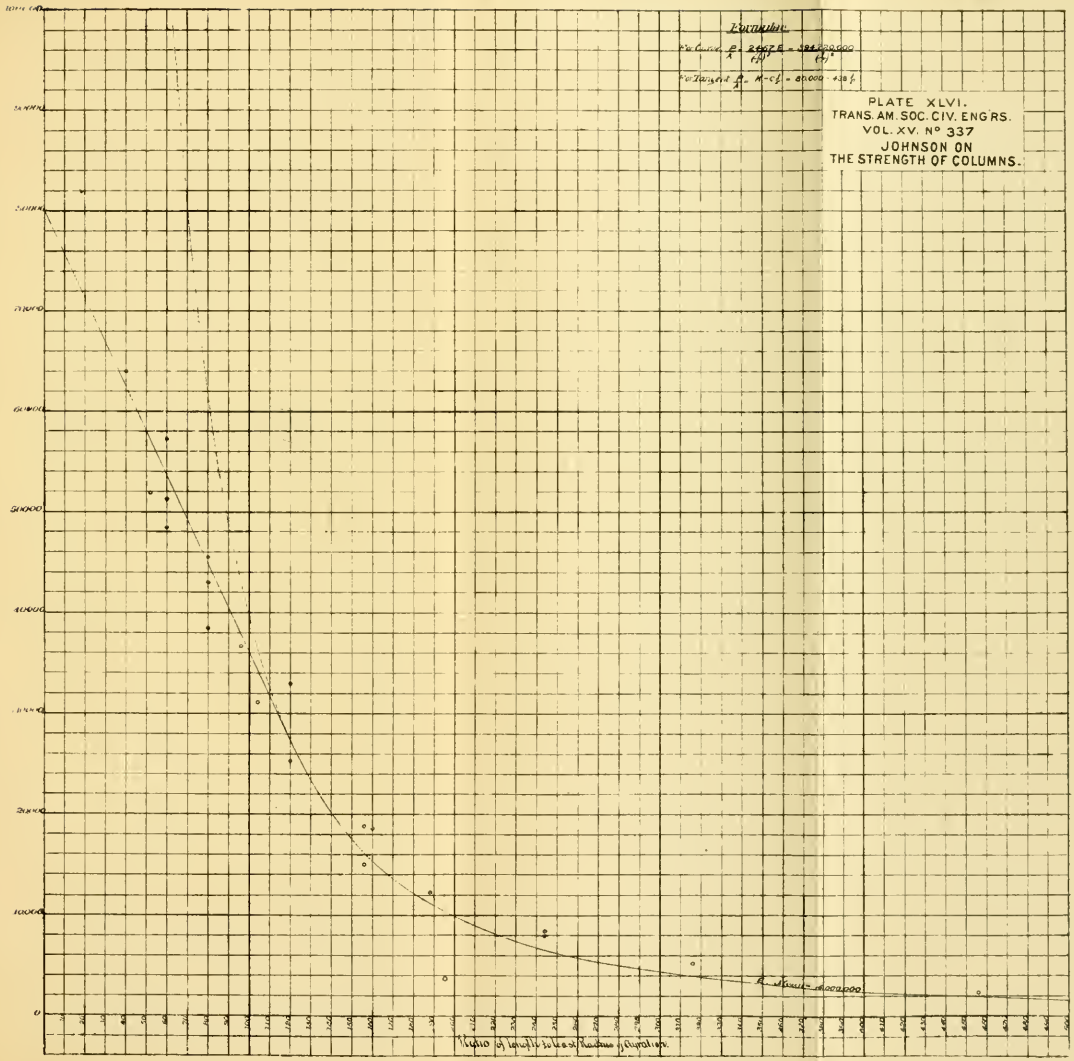
HARD STEEL

FLAT ENDS



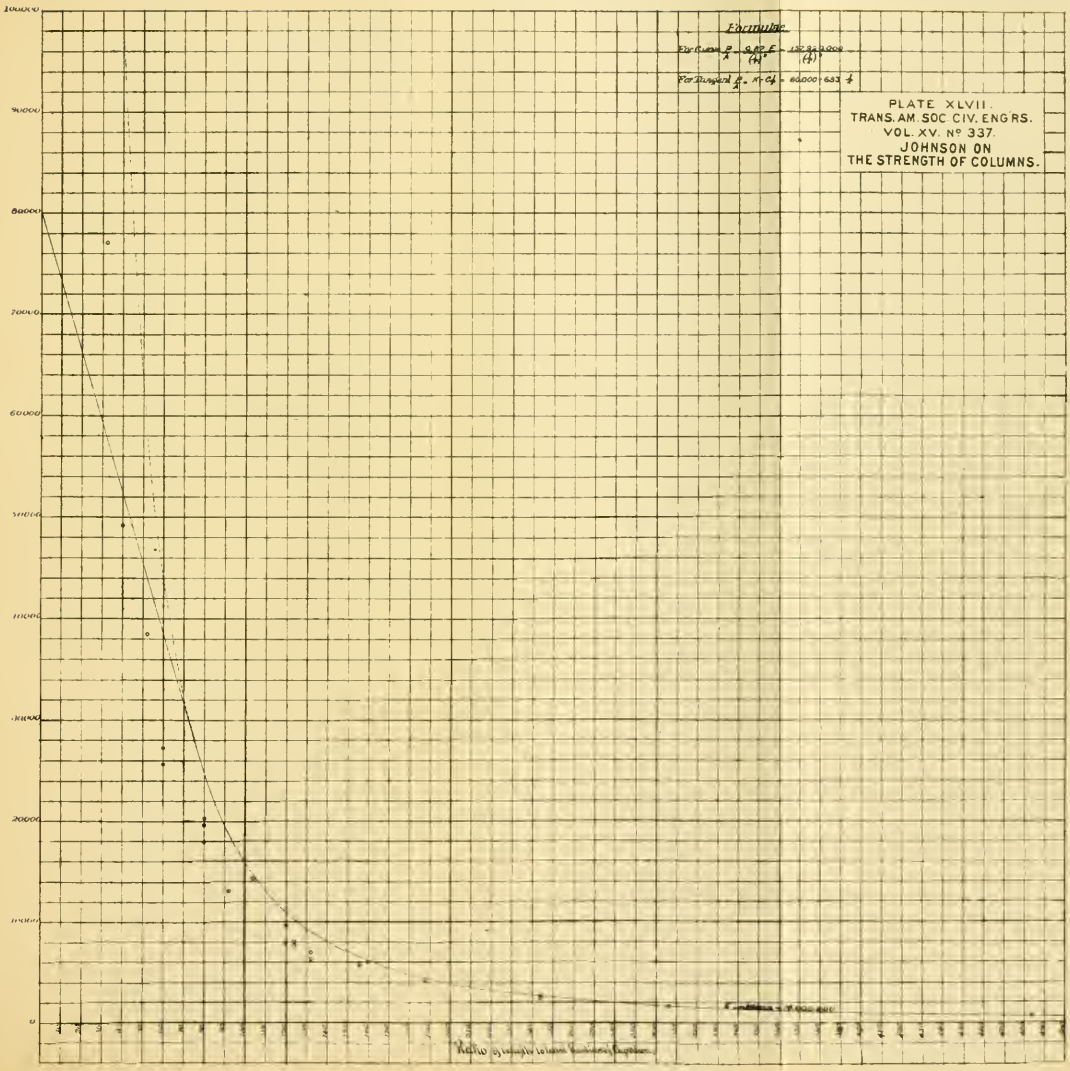
CAST IRON

FLAT ENDS.



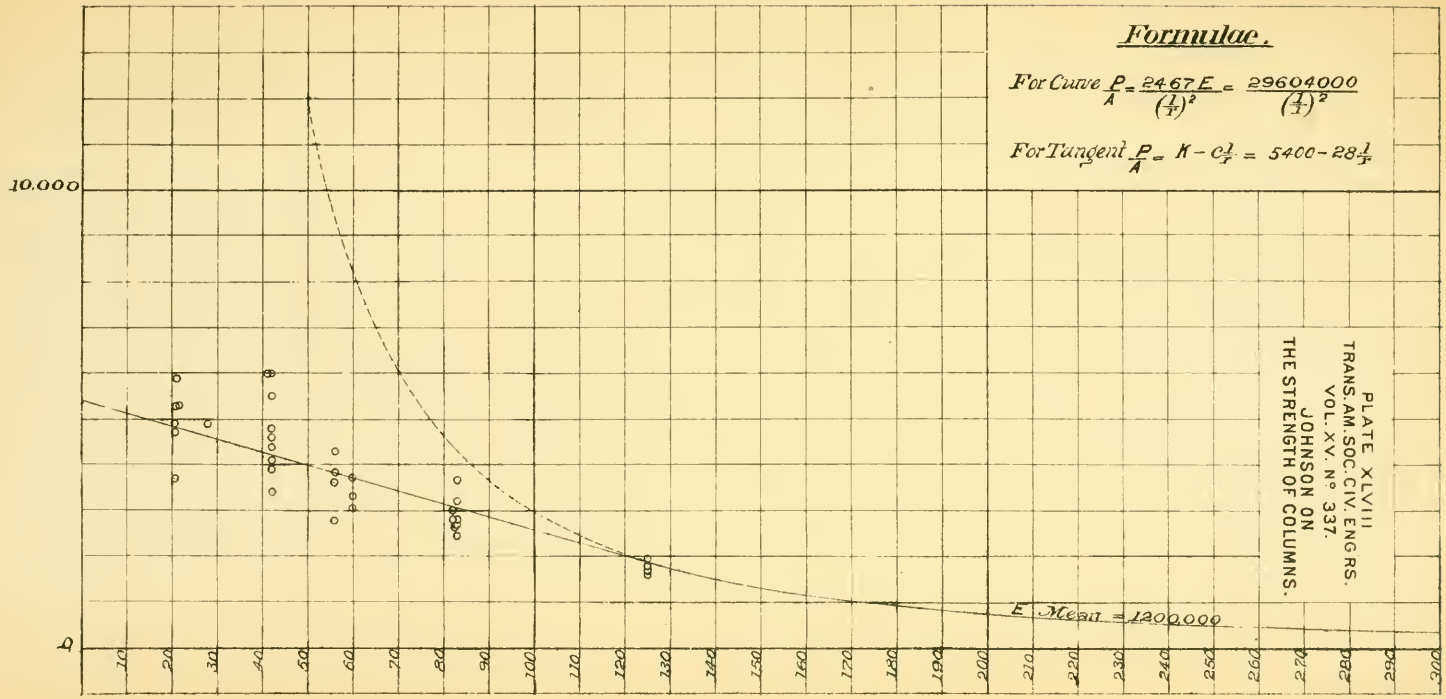
CAST IRON

ROUND ENDS.



OAK

FLAT ENDS



FLAT ENDS

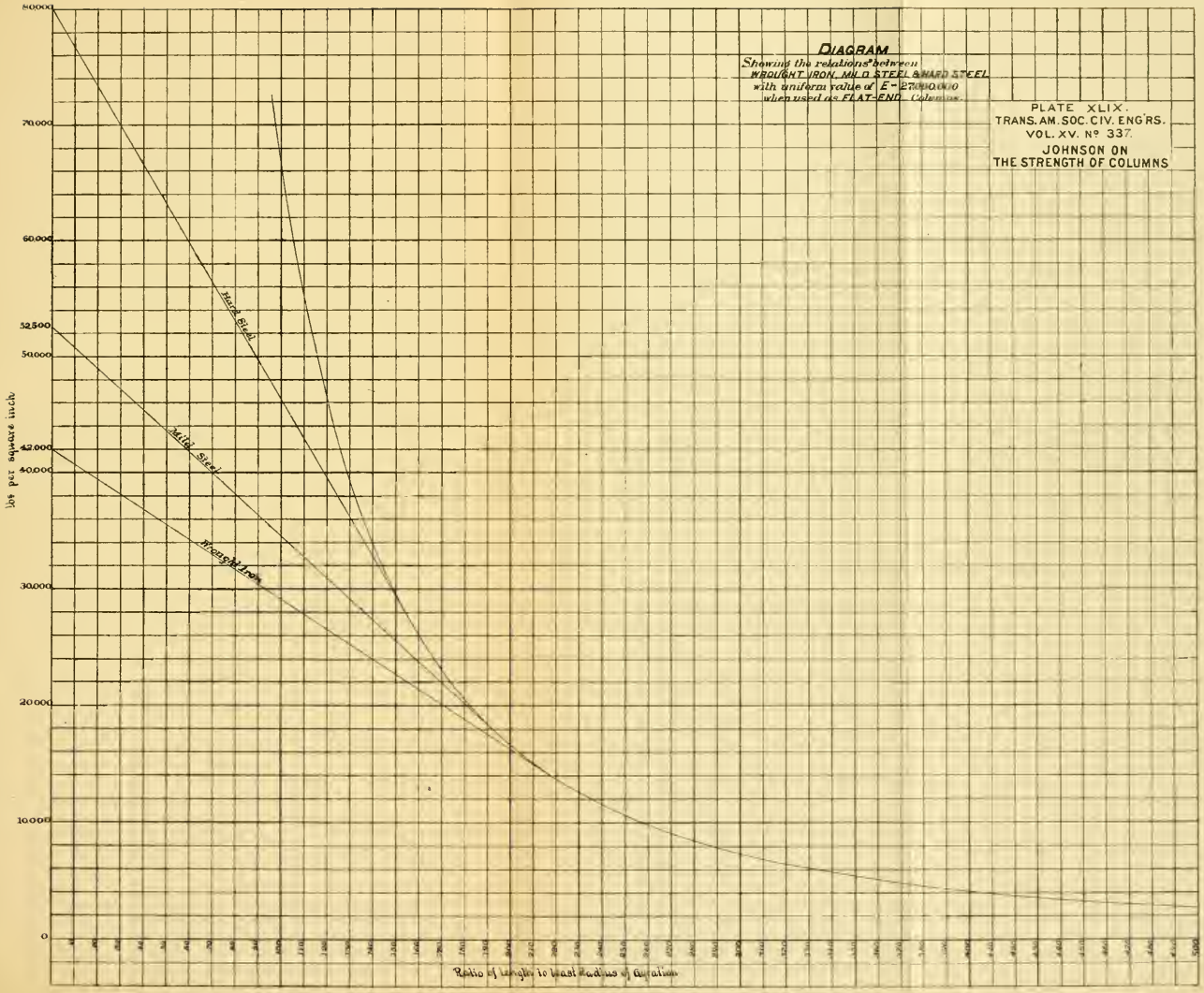


DIAGRAM
Showing the relations between
WROUGHT IRON, MILD STEEL & HARD STEEL
with uniform value of E = 27000000
when used as FLAT-END Columns.
PLATE XLIX.
TRANS. AM. SOC. CIV. ENG'RS.
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JOHNSON ON
THE STRENGTH OF COLUMNS
Hard Steel
Mild Steel
Wrought Iron
lbs per square inch
80,000
70,000
60,000
52,500
51,000
42,000
40,000
30,000
20,000
10,000
0
Ratio of length to least radius of Gyration

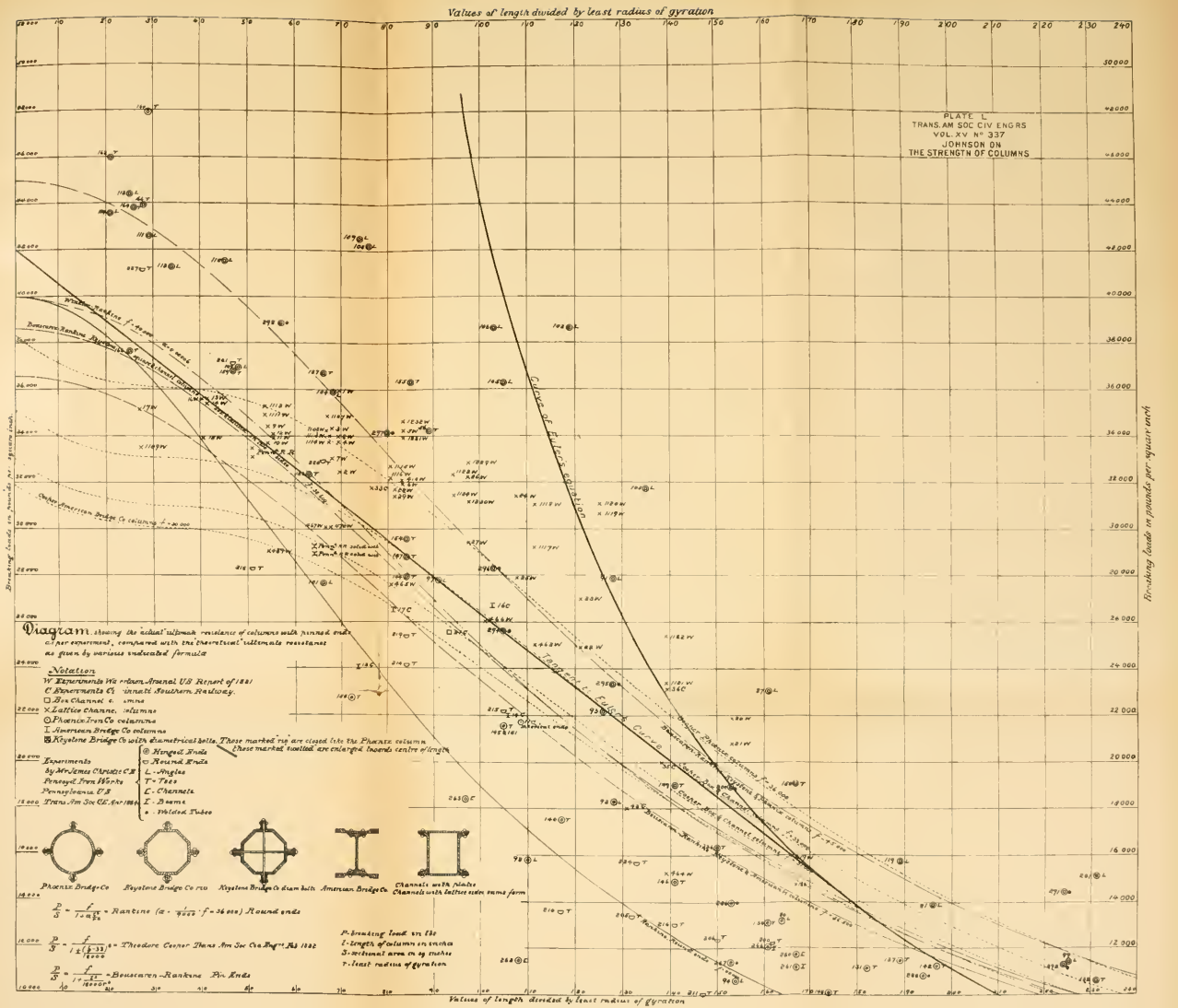
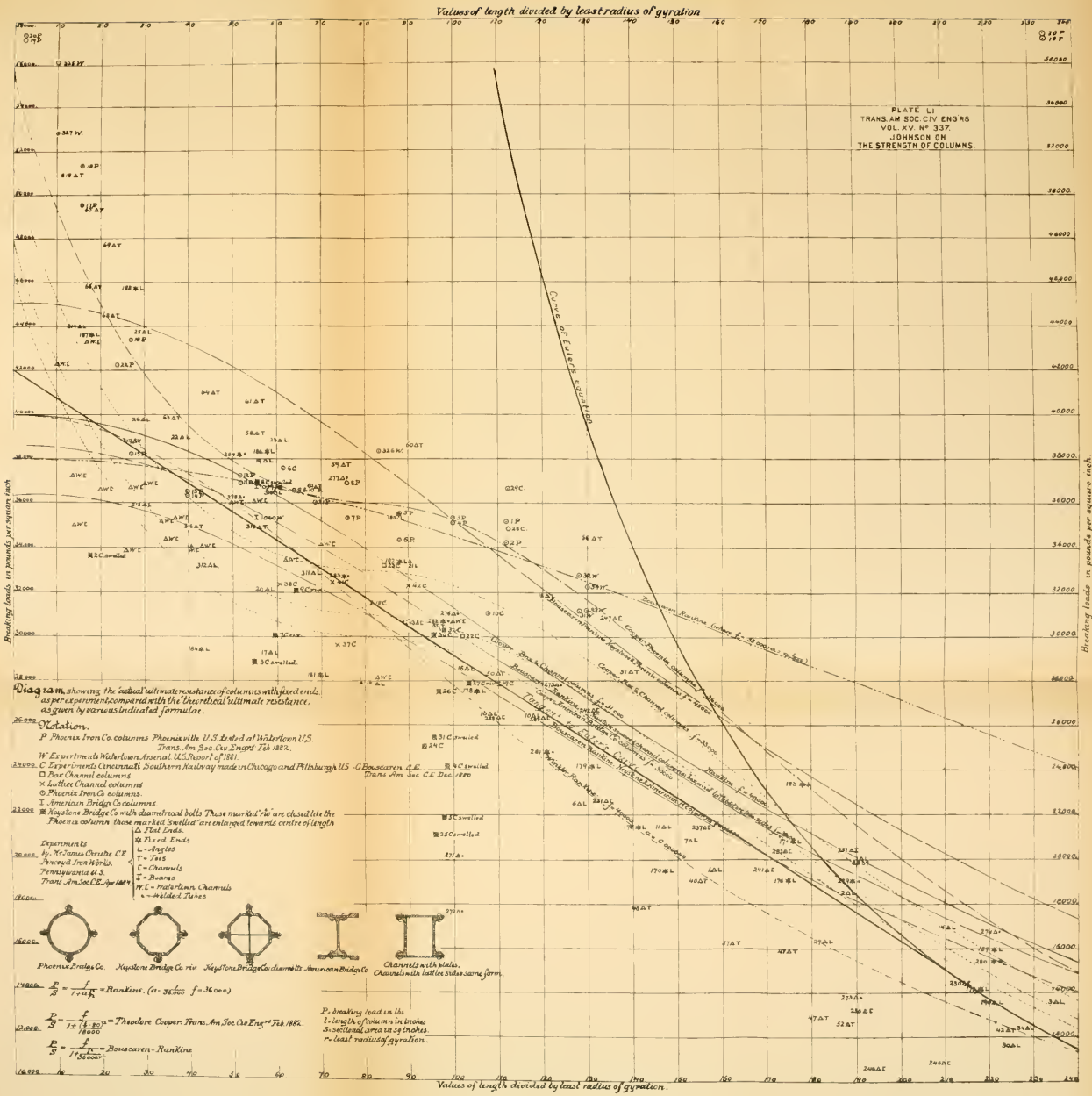


PLATE L
TRANS. AM SOC CIV ENGRS
VOL. XV Nº 337
JOHNSON ON
THE STRENGTH OF COLUMNS
Values of length divided by least radius of gyration
Breaking loads in pounds per square inch
Diagram showing the actual ultimate resistance of columns with pinned ends as per experiment, compared with the theoretical ultimate resistance as given by various indicated formulæ
Notation
W Experiments Watertown Arsenal U.S. Report of 1881
C Experiments Cincinnati Southern Railway.
□ Pin Channel columns
X Lattice Channel columns
⊙ Phœnix Iron Co columns
I American Bridge Co columns
⊠ Keystone Bridge Co with diametrical bolts. These marked ⊠ are closed into the Phœnix column
⊗ Hinged Ends
○ Round Ends
These marked thus ⊗ are enlarged beyond centre of hinge
Experiments by Mr James Christie C.E. Pencoyd Iron Works Pennsylvania C.E. Trans. Am Soc C.E. Apr 1884
L. Angles
T. Tees
C. Channels
I. Beams
s. Welded Tubes
Phœnix Bridge Co
Keystone Bridge Co rou
Keystone Bridge Co diam bolt
American Bridge Co
Channels with plates
Channels with lattice ribs same form
P/S = f/(1+a l²/r²) = Rankine (a = 1/9000, f = 36000) Round ends
P/S = f/(1+l²/(3000 r²)) = Theodore Cooper Trans Am Soc Civ Eng Apr 1882
P/S = f/(1+l²/(4000 r²)) = Bouscaren-Rankine Pin Ends
P. breaking load in lbs
l. length of column in inches
S. sectional area in sq inches
r. least radius of gyration
Curve of Euler's equation
Rankine Formula
Bouscaren Rankine Formula
Cooper Pin Ends
American Bridge Co Columns
Cooper Pin Channel columns
Cooper Lattice Channel columns
Keystone Diameter bolt columns
Keystone Round ends columns
Phœnix Columns
Keystone Round ends
Phœnix Columns
Keystone Diameter bolt
Cooper Lattice Channel columns
Cooper Pin Channel columns
Cooper Lattice Channel columns
Cooper Pin Channel columns
Cooper Lattice Channel columns
Cooper Pin Channel columns



Values of length divided by least radius of gyration
PLATE LI
TRANS. AM. SOC. CIV. ENG'RS
VOL. XV. No. 337.
JOHNSON ON
THE STRENGTH OF COLUMNS.
Curve of Euler's equation
Breaking loads in pounds per square inch
Diagram, showing the actual ultimate resistance of columns with fixed ends, as per experiment, compared with the theoretical ultimate resistance, as given by various indicated formulae.
Notation.
P Phoenix Iron Co. columns Phoenixville U.S. tested at Watertown U.S. Trans. Am. Soc. Civ. Engrs Feb 1882.
W. Experiments Watertown Arsenal U.S. Report of 1881.
C. Experiments Cincinnati Southern Railway made in Chicago and Pittsburgh U.S.
G Bouscaren C.E. Trans Am Soc C.E. Dec 1880
□ Box Channel columns
× Lattice Channel columns
⊙ Phoenix Iron Co. columns.
I American Bridge Co. columns.
■ Keystone Bridge Co with diametrical bolts Those marked "rie" are closed like the Phoenix column those marked "swelled" are enlarged towards centre of length
Experiments by Mr. James Christie C.E. Pencoyd Iron Works. Pennsylvania U.S. Trans. Am. Soc. C.E. Apr 1884.
△ Flat Ends
✱ Fixed Ends
L - Angles
T - Tees
C - Channels
I - Beams
W.C. - Watertown Channels
• - Welded Tubes
Phoenix Bridge Co.
Keystone Bridge Co. rie
Keystone Bridge Co. diametrs
American Bridge Co
Channels with plates. Channels with lattice sides same form.
$\frac{P}{S} = \frac{f}{1+a\frac{l}{r}}$ = Rankine. (a = $\frac{1}{36000}$ f = 36000)
$\frac{P}{S} = \frac{f}{1 \pm \frac{(\frac{l}{r}-80)^2}{18000}}$ = Theodore Cooper Trans. Am. Soc. Civ. Eng'rs Feb 1882.
$\frac{P}{S} = \frac{f}{1+\frac{l}{36000r}}$ = Bouscaren - Rankine
P = breaking load in lbs
l = length of column in inches
S = sectional area in sq inches.
r = least radius of gyration.
Values of length divided by least radius of gyration.

AMERICAN SOCIETY OF CIVIL ENGINEERS.
INSTITUTED 1852.

TRANSACTIONS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

338.
(Vol. XV.—July, 1886.)

NEW FORMULA FOR COMPRESSION MEMBERS.

BY PROFESSOR R. KROHN.
PRESENTED APRIL 7TH, 1886.

The determination of the permissible strains upon compression members has not yet been rationally and satisfactorily solved. Neither theoretical deductions nor practical tests have given us formulas free from objections.

Upon the assumption that the compressive force acts exactly in the direction of the axis of the member, theory teaches us that a bending or deflection of the member, and consequently the danger of crippling, can only occur when the external force has reached a certain limit, and as long as the force remains below this limit the member will only be strained by simple compression. Such a result, however, does not agree with the results of practical experiments, which rather show a deflection of the struts at almost any applied strain, and rupture under loads which, by theory, should not even produce deflection. This contradiction of the theory and the results of experiments, shows that the assumption of the theory that the external forces act through the axis of the mem-

bers, is untenable in practice. It is impossible, with the greatest care, to attain this condition; the unavoidable inaccuracies of workmanship and inequalities of the material render it impossible, even in carefully prepared test pieces, to secure this theoretical condition; how much more so then in practical bridge members?

Why, not, then, from the beginning, assume that the external forces do not coincide with the axis of the struts, but that the stresses are eccentric to this axis? The resultant formulas will then contain a value for the original eccentricity. Is it possible to determine this value from the results of experiments?

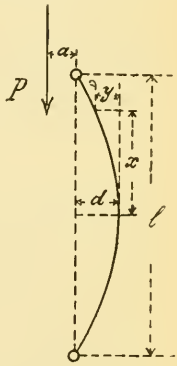
It is evident that the original eccentricity cannot be confined to any definite law. The results of experiments show great irregularities and wide variations. It is only possible then to determine and rely upon the upper limit of this original eccentricity for the ordinary conditions of practice. This determination would be a difficult task. We could not use the usual compression tests extending to the crippling point, but only such tests as determine the deflections of the struts while the fiber strains are within the elastic limit. But even this method would give us no reliable results, as the fiber strains would depend so much upon the accuracy of the workmanship and the carefulness with which the end connections are made. If an upper limit for this eccentricity were obtained from a particular series of experiments, we have no surety that it would apply to any other series of struts used in any particular structure.

While the foregoing theoretical and practical methods seem unsatisfactory, it would appear that we may take advantage of the following practical consideration to reach a solution.

The tension and compression members used in our structures are made with equal care in the selection and arrangement of the component parts and in manufacturing the same. For similar conditions of practice, the original eccentricity of the lines of stress occurs in tension as well as in compression members, whether due to want of uniformity of the material or to inaccuracies in centering the connections. The additional strains produced by this condition of eccentricity are naturally smaller in the tension than in the compression members. Our experience teaches us that the original eccentricity is generally so small that the additional strains produced by it in the tension members may be neglected.

If we compare then the action of an external force upon a tension and a compression member having the same eccentricity, it will be possible to determine an upper limit for the strains in the compression members with the same relative precision and accuracy with which the strains in the tension members can be calculated.

Let Figure 1 represent a strut with its ends secured in such a manner that it is free to change the inclination of its axis at the ends.



Call its length l.

Let a force, P, be applied at a distance a from the axis of the strut.

$S =$ sectional area of strut.

$I =$ its moment of inertia.

$r =$ least radius of gyration.

$e =$ distance of extreme fiber from the neutral axis

$d =$ deflection of the elastic line.

$E =$ modulus of elasticity of the material.

x and $y =$ co-ordinates of deformed axis.

Then for any point in the deformed axis we have the following equation of moments:

$$M = P\,[\,a + d - y]$$

and for the equation of the elastic line:

$$\frac{d^2 y}{d x^2} = \frac{P}{E I}\,[a + d - y]$$

Integrating this last equation twice, considering that for $x = 0$, $y = 0$ and $\frac{d y}{d x} = 0$ also, we get the following:

$$\frac{y}{a + d} = 1 - \cos.\left[\,x\sqrt{\frac{P}{E I}}\,\right]$$

If $x = \frac{l}{2}$, $y = d$, and we get:

$$\frac{d}{a + d} = 1 - \cos.\left[\frac{l}{2}\sqrt{\frac{P}{E I}}\,\right] \text{ or}$$

$$a + d = \frac{a}{\cos.\left[\frac{l}{2}\sqrt{\frac{P}{E I}}\,\right]} \qquad (1)$$

The greatest compression in the extreme fiber will be at the middle of the strut. Denote this by C:

$$C = \frac{P}{S}\left[1 + \frac{(a+d)\,e}{r^2}\right] \tag{2}$$

Combining equations (1) and (2):

$$C = \frac{P}{S}\left[1 + \frac{a\,e}{r^2 \cos.\left[\frac{l}{2}\sqrt{\frac{P}{E\,I}}\right]}\right] \tag{3}$$

The cosine in this formula may be developed into a progression, and by remembering that $\frac{l}{2}\sqrt{\frac{P}{E\,I}}$ will be smaller than unity,* we can obtain a very close approximation by taking

$$\cos.\left[\frac{l}{2}\sqrt{\frac{P}{E\,I}}\right] = 1 - \frac{1}{8}\frac{l^2\,P}{E\,I}$$

Substituting this value in equation (3), we get:

$$C = \frac{P}{S}\left[1 + \frac{a\,e}{r^2\left(1 - \frac{1}{8}\frac{l^2\,P}{E\,I}\right)}\right] \tag{4}$$

If a similar member were strained in tension by the force P acting at the same eccentricity a, the bending moment at no point of the axis would be greater than $P\,a$; and the greatest tension fiber strain would be

$$T = \frac{P}{S}\left[1 + \frac{a\,e}{r^2}\right] \tag{5}$$

Equations (4) and (5) then represent the relative maximum strains produced on similar compression and tension members by similar forces.

If we call $\frac{C}{T} = n$, n denotes the ratio between the induced strains, or how many times greater the maximum compression is than the maximum tension under similar conditions in practice.

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*If the original eccentricity equals zero, we have for the load producing rupture $\pi^2\,\frac{E\,I}{l^2}$. As, however, there is always some eccentricity, we can assert from both theory and practice that the load R, producing rupture, will be

$$R < \pi^2\,\frac{E\,I}{l^2} \text{ or } \frac{l}{2}\sqrt{\frac{R}{E\,I}} < \frac{\pi}{2}$$

If the strains are kept within the highest allowable limit, the load P must be far less than R; we can therefore for all practical cases assert that

$$\frac{l}{2}\sqrt{\frac{P}{E\,I}} < 1.$$

From (4) and (5) we get:

$$n = 1 + \frac{\frac{1}{8}\frac{l^2 P}{E I}}{1 - \frac{1}{8}\frac{l^2 P}{E I}} \times \frac{\frac{a e}{r^2}}{1 + \frac{a e}{r^2}} \tag{6}$$

The fraction $\frac{\frac{a e}{r^2}}{1 + \frac{a e}{r^2}}$ can never be greater than unity, whatever value the original eccentricity a may have. We have therefore for the upper limit of the value of n, the following equation:

$$n = \frac{1}{1 - \frac{1}{8}\frac{l^2 P}{E I}} \tag{7}$$

By maintaining this ratio between our working strains in compression and tension, we can neglect equally well the eccentricity for compression members as in practice we do for tension members.

Calling $k = \frac{P}{S}$ the allowed unit strain in tension members, the allowed unit strain in compression members will be

$$\frac{P}{S} = \frac{k}{n} \tag{8}$$

From (7) and (8) we get for compression

$$\frac{P}{S} = k\left[1 - \frac{1}{8}\frac{l^2 P}{E I}\right]$$

Substituting for I its value $S r^2$, we get:

$$\frac{P}{S} = \frac{k}{1 + \frac{1}{8}\frac{k}{E}\frac{l^2}{r^2}} \tag{9}$$

which agrees in its general form with Rankine's formula; the coefficient for $\frac{l^2}{r^2}$ however is not constant, but varies with $\frac{k}{E}$; that is, it increases with increased deformation of the material.

For example: With wrought-iron, calling $k = 10\,000$ pounds per square inch, and $E = 26\,000\,000$ pounds, the comparative working strain for compression members should be

$$\frac{P}{S} = \frac{10\,000}{1 + \frac{1}{20\,800}\,\frac{l^2}{r^2}}$$

For steel, with the same modulus of elasticity, but using a higher unit strain for tension, viz., $k = 15\,000$, we get:

$$\frac{P}{S} = \frac{15\,000}{1 + \frac{1}{13\,800}\,\frac{l^2}{r^2}}$$

which shows that for long and slender columns, whose ratios for $\frac{l^2}{r^2}$ are large, steel cannot be used with the same advantage as in short, massive columns, or as in tension members.

It will be necessary, in order to use steel economically for compression members, to employ such shapes as will give a large radius of gyration in proportion to the length of the struts.

For cast-iron:

$$k = 10\,000 \quad E = 13\,000\,000$$

$$\frac{P}{S} = \frac{10\,000}{1 + \frac{1}{10\,400}\,\frac{l^2}{r^2}}$$

For wood:

$$k = 1\,000 \quad E = 1\,200\,000$$

$$\frac{P}{S} = \frac{1\,000}{1 + \frac{1}{9\,600}\,\frac{l^2}{r^2}}$$

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TRANSACTIONS.

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(Vol. XV.—August, 1886.)

ON THE WORK DONE FOR THE PRESERVATION OF THE DAM AT HOLYOKE, MASS., IN 1885, AND ON SOME STUDIES FOR A NEW STONE DAM FOR THE SAME PLACE.

By CLEMENS HERSCHEL, M. Am. Soc. C. E.

READ FEBRUARY 17TH, 1886.

Friends of mine have thought that a description of the work done at Holyoke, Mass., on the dam of the Holyoke Water Power Company, in the summer of 1885, would prove interesting to the profession. I have had my doubts about it, for the reason that this was one of that class of engineering works which cannot readily be repeated; which makes no show after it is done—indeed, leaves little or no trace upon the surface of its very existence; and involves no search or delving in the hitherto unexplored regions of mathematical or other sciences. But if this record of a highly useful work, well done, be

> "Something that perhaps another,
> Sailing o'er life's solemn main,
> A forlorn and shipwrecked brother,
> Seeing, shall take heart again,"

I shall be glad to have written it. And for the purpose of adding other possibly interesting or useful matter, I have included some historical accounts of the dam at Holyoke—some lessons that may be learned from thirty-six years of its life—together with an account of some experiments made in the line of selecting a design for a new stone dam for the same place. I have been the more ready to do this, as the dam at Holyoke, although the largest over-fall dam in the world, as far as I know, has not, that I am aware of, hitherto been described in engineering literature.

Water Power at Holyoke, Mass.

The Holyoke dam and water power is the outcome of that spirit of enterprise for manufacturing, which swept like a great wave over the New England States between the years 1820 and 1850, consequent upon the successful introduction of cotton manufacturing at Waltham, Mass., and at other places. The works of the Hadley Falls Company, in founding the present City of Holyoke, were built, moreover, at the very time of extreme high water-mark of this era of enterprise for manufactures. The water power at Lowell, Mass., had come under the control of a company, organized simply and solely to administer a water-power, in 1845. Two years later saw the completion of the dam at Lawrence, Mass., by the Essex Company, another water-power company. And the same year, 1847, a charter was obtained, creating the Hadley Falls Company, for the purpose (amongst others) of constructing and maintaining a dam across the Connecticut River, at the point where now is Holyoke. It is but just to say, in passing, that this last was the work, principally, of James K. Mills, then a merchant of Boston, but born and brought up in that rugged school of life, "up among the Berkshire Hills." He became the leader in the subsequent work and enterprise, and remained so until the year 1857, ill-fated to many another such a pushing, restlessly active, mind and man.

In 1853, the directors of the company published a description of the dam and canals, and of the young city, which is now out of print. It is in many ways interesting reading at the present day, wherefore I do not hesitate to quote from it. After describing the soil and drainage area of the Connecticut River, its central location and other advantages, and noting the fact that while in Massachusetts every fall in the smaller rivers, "indeed every 'privilege' upon the smallest and most insignificant streams have been seized upon for the use of some mill or factory,

the noble Connecticut had been long almost neglected," they go on to say: "This neglect would be inexplicable, were it not obvious that the extraordinary magnitude of the enterprise, required, in a corresponding degree, more than ordinary forethought, skill and capital, for its accomplishment. But it is equally obvious that such an enterprise, when carried out, should be successful and productive in a corresponding degree."

Under a charter granted in 1792, the Connecticut River had been made navigable to small boats and rafts, eventually, up to Wells River, Vermont; and up past what is now Turner's Fall, Mass., probably prior to 1800. In 1797 the tolls had already amounted to about $5 000. The works at South Hadley, Mass., opposite the present City of Holyoke, were the property of the "Proprietors of the locks and canals on the Connecticut River." This company had had its ups and downs, like many another. After a lot of assessments on the "proprietary shares," just as these things go now-a-days, the tolls began to come in, and later on, the dividends to go out. In 1815 the tolls were $11 000; in 1817, $15 000; in 1833, $20 000, with $15 000 of dividends paid that year. This was probably the best year the company saw, for with the facilities afforded by the railroads built soon after, the crude navigation afforded by the works of the proprietors of the locks and canals on the Connecticut River could in no way compete. But in 1848 it was ready to and did sell and convey its real estate to the Hadley Falls Company, the individual stockholders at the same time selling their stock to the principal men in the new company.*

The First Dam at Holyoke.

Quoting from the pamphlet above named: "It was at first contemplated to throw across the river a temporary dam, which, while it would

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* As an example of how things were done in the olden time, I mention the fact that during the process of conveying the property and franchises of the proprietors to the present Holyoke Water Power Company, in 1883, it became my duty to look up the stock. Do what I would, I could not find more than 503 shares, and yet the property had been divided into 504 shares in 1792. There was no help for it but to begin at the beginning and search the records, when behold:

I, the within named James Bull, of Hartford, in the State of Connecticut, in consideration of a valuable sum of money, viz.: two hundred and twenty dollars ($220), received to my full satisfaction, of Jonathan Dwight, Esq., Treasurer of the Lower Locks and Canals on Connecticut River, the receipt whereof I do hereby acknowledge, do assign and make over all my right and title to the within mentioned share, No. 80, and all privileges and rights to which I am entitled by virtue thereof, to him the said Jonathan Dwight, Esq., or his

serve as a protection to the erection of one more substantial below it, would answer the purpose of the company until such permanent dam should be completed. The first dam was accordingly built with less regard to strength than the result proved would have been prudent. It was not able to resist the force of the river, and was carried away after the gates were closed. The shutting of the gates occurred earlier than had been designed, in consequence of a freshet in the river." To this I may add, on reliable authority, that it was, after all, fortunate that the dam gave way, because the coffer-dam upstream from the head gate-house was rapidly breaking up—the head gates were not yet in their grooves, nor was the upper level canal done—and had this coffer-dam failed, it would have turned the whole river over the site of the projected new city, and would have done incalculable damage. I know of no drawing that would show the construction of the first dam at Holyoke. The gates were shut at about 10 A. M., November 16th, 1848; the water had risen to within 2 or 3 feet of the top by 3.20 P. M.; when all but about 75 feet at one end and 150 feet at the other, rolled over and floated down stream on the crest of a wave about 8 feet high. Some newspaper communications with regard to its failure appeared in the New York *Tribune* of November 20th, 21st and 25th, 1848, but they are not conclusive as to the cause.

Tradition has it, that this dam was, in its framing, very much like the coffers herein portrayed, and used on the dam in 1885, and that the principal cause of the failure was the too steep slope given the upstream face of the dam. The loss to the company by the giving way of this

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successors in office, to have and to hold to him and them so long as the corporation shall remain a body politic.

Witness my hand and seal, this 11th day of December, Anno Domini, 1807.

JAMES BULL. [SEAL.]

Signed, sealed and delivered in the presence of } THOMAS BULL, CHARLES BULL.

STATE OF CONNECTICUT, Hartford County, Hartford. } ss.:

December 11th, 1807, then personally appeared James Bull above-named, and owned the foregoing instrument to be his free act and deed.

Before me,

ELISHA COLT, Justice of the Peace.

In other words, the worthy Treasurer, instead of watering the stock, which is the modern pastime, had valiantly commenced to condense it, and had started the bull movement by boiling the stock down to the extent of one share.

first dam was at first called $50 000 or $100 000, but was finally stated, on what seems good authority, as having amounted to $38 000. Day labor at the time was about 75 cents a day, and a strike occurred on reducing this to 70 cents a day.

Second and Present Dam at Holyoke.

Quoting again: "The company immediately proceeded to the erection of the present dam upon a very different and a much stronger plan, which, as it has already defied the strength of the current of the river for three years, will no doubt remain permanent indefinitely. This dam was begun and finished in the summer of 1849. Its length is 1 017 feet, about one fifth of a mile. At the two ends are abutments of heavy masonry, the amount in both being nearly 13 000 perches. Between these abutments it is composed of heavy timbers, the smallest being 12 inches square, which are built up in such a way as to present on the upper side a surface of plank inclined at an angle of 21 degrees 45 minutes to the water of the river. The timbers which cross the river transversely, are supported by other timbers at right angles with them, which are arranged in 170 sections, 6 feet apart. The ends of these timbers, parallel with the course of the river, are spiked to the solid rock at the bottom of the channel with 1¼-inch iron bolts, of which there are nearly 3 000. Four million feet of timber are contained in the structure, all of which, being under water, is protected from decay. Gravel was filled in and well pounded down at the foot of the dam, which is still further protected by the addition of a mass of concrete. As the timber-work went up, the whole foundation, 90 feet in extent, and all open spaces were packed solidly with stone to the height of 10 perpendicular feet. The planking of the upper portion of the dam was doubled (trebled) to a thickness of 18 inches of solid timber (3 layers of 6 inches each) all trenailed, spiked, and strongly bound together. The rolling top or combing was then covered with sheets of boiler-plate, placed side by side, and extending the whole length of the dam. The graveling in the bed of the river begins 70 feet above the dam, and is continued over 30 feet or more of its sloping surface, which is 92 feet in length from the foot to the crest of the dam.

"During the construction of the dam, the water was allowed to flow through gates in it 16 by 18 feet, of which there were 46 in all, when the work was finished. At twenty-two minutes before one o'clock, in the

afternoon of October 22d, 1849, the engineer gave a signal and half of the gates were closed, another signal immediately followed and the alternate gates were also closed—the river ceased its flow, until its water, gradually collecting, rose upon the face of the dam, and finally fell in a broad sheet over its crest.

"The firm basis upon which this dam stands, founded, as it is, upon the solid rock at the bottom of the river; the strength and solidity of the structure by which the several parts support each other and the whole is bolted to its foundation; the thick bed of gravel on the upper end of the dam, and the filling in with stone between the timbers; the substantial manner in which the work was executed under the superintendence of careful engineers; the effect of the water upon the material of which it is constructed, rendering it practically imperishable; and the safety with which it has passed through the severe trials of the freshets of three years—these things leave no room for doubt as to its permanence and security.

"At the western end of the dam, as is indicated upon the plan at the end of this pamphlet, the water of the river is drawn out in a canal for the supply of the mills. The water is conveyed into this canal by means of 13 gateways. There is also a stone lock. The sides of the canal are built of solid masonry. The width is 140 feet at the bottom and 144 feet at the surface. The canal is designed for 20 feet of water. * * * * * * The exact fall from the river above the dam to the still water below is 59.9 feet. Of this, 20 feet are used by the mills on the upper level, leaving a fraction less than 40 feet fall for the most southerly mill on the lower level. The mills on the northern end of the lower level, of course, do not have so much fall, as they deliver the water directly into the river, which is higher just under the dam than below, on account of the rapids. All of the mills at the lower level, however, will have at least 30 feet of effective fall throughout the year." At a later day this project was changed to a system of three levels, the middle set of mills having 12 feet fall. There are to-day five different kinds of falls used from the canals of the Holyoke Water Power Company: from each of the three levels directly into the river; from the first into the second, and from the second into the third level.

A cross-section of the dam accompanies the description above given, which has been reproduced on Plate LII. Another illustrated description of the work, showing also the apparatus used for dropping the gates,

PLATE LII
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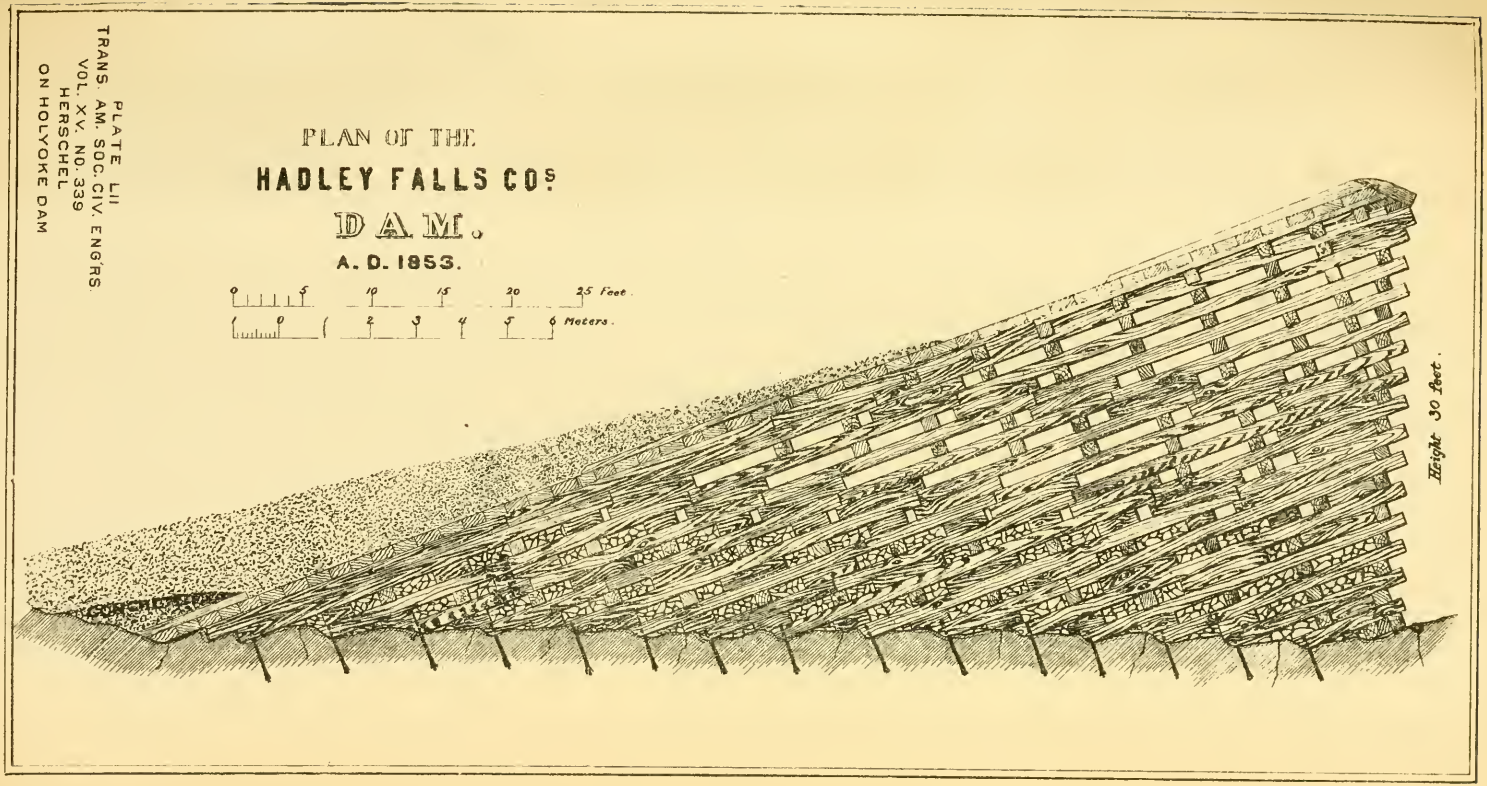

may be found in the Springfield *Republican* of March 6th, 1850, printed also in the *Scientific American* of the preceding week. The total cost of the dam is given at $150,000, which would represent at least $250,000, I should judge, at the present day. This account states: "The dam leaks but very little, not a whit more than is desirable for its preservation." And the Springfield *Republican* of October 23d, 1849, describing the closing of the gates and completion of the dam had said: "The dam leaks a little, not so much as the one which went out last year. This is considered no fault, as a sufficient leak is necessary to keep all of the timbers of the dam bathed in water to prevent rot. If it does not leak enough for this it will be made to leak more by boring holes through." How far all these anticipations of a preservation of the dam by its being constantly under water were realized, will appear presently. The agent of the company at the "New City" was Mr. John Chase. The chief engineer was Philander Anderson, who entered West Point in 1827, but did not graduate. In the designing of the works at Holyoke, in the excellent lay-out of the canals and streets of the new city, Mr. Anderson has left an imperishable monument to the good qualities in him. His was one of those natures which are their own worst enemy, and it is not known that he did later important work. A Mr. Foote is mentioned as assistant engineer, and of A. C. McNary, superintendent of mechanics, it is said, that "to him great praise is due for the perfection with which the work was accomplished."

Experience of 1849 to 1868.

November 12th, 1849, already saw 6 feet of water over the new dam, and the windows in Springfield, eight miles away, rattled at the rate of 128 vibrations per minute in consequence of the sheet of water passing over without opportunity being afforded for the air to pass freely underneath from one abutment to the other. It was even claimed that the noise made by the water falling over the new dam was heard in Hartford, Conn., 34 miles away. The following May there was 8½ feet of water on the dam. Four years later, 1854, there was 10¼ feet, and in April 1862, there was 12½ feet, which sent the water through the doors of the gate-house, and which has remained the maximum to date. The abutments and gate-house construction had provided for only ten feet as a maximum, whereupon the abutments were raised 2 feet, and finally, in 1877, the whole gate-house was raised. The dam is built on a ledge

of red slate, which in some places turns to hard red sandstone. This dips at an angle of about 30 degrees with the horizontal, the low part of the seam being down-stream from the dam, so that the water, as it falls over, strikes the seams of the ledge in the best possible position for overturning the layers of rock, and for sending them on down-stream. The perpendicular fall of such a body of water for 30 feet would, naturally, very soon cut out a ledge of this description, and, added to this, came the effect of ice and logs going over, and striking on the bottom, constantly in about the same line across the river. In a case of this sort I have in mind, the hard ice going out in mid-winter, and falling only 18 feet, cut through an apron of 12-inch square timbers in a few hours, the sticks looking as if they had been pounded off with the back of an ax. Logs going over did mischief in another way. At the foot of any perpendicular fall of water there is what is called an undertow towards the dam. When the water strikes upon the rock below, with all the velocity due the height it fell, this velocity, or work stored up in the mass, must be absorbed in some way, and the volume of water made to pass off. No intelligent guidance being provided for it, the water dashes and flows about in any and in every direction, away from, primarily, not much more than towards the dam. Huge logs can be observed banging into the dam; then caught in another current and carried away from it; then again propelled against the dam, like a battering ram, and so on, frequently for a considerable length of time, before the log goes on down-stream. Be this as it may, in 1868, or when the Holyoke dam was nineteen years old, unpleasant rumors arose as to its security. There were depressions in the line of the crest, and sundry fishermen and others had seen thus and so. In point of fact, various examinations made soon after by adventurous parties who crawled through the dam, behind the sheet of water which in those days veiled the front face from inspection, revealed the unpleasant fact that the logs above named, striking the front face of the dam end on, must have got caught at times between the timbers of the dam, and the sheet of water then falling on them had apparently acted like a great power at the end of a huge crowbar to pry out the front face timbers. The ledge had also been washed out in front to a depth of 20 to 25 feet, and working in back under the dam, it had become undermined in places. This front lowest course of timbers, or the heel of the dam, had been very carefully built of three 15-inch square timbers all the way across the river, but when deprived

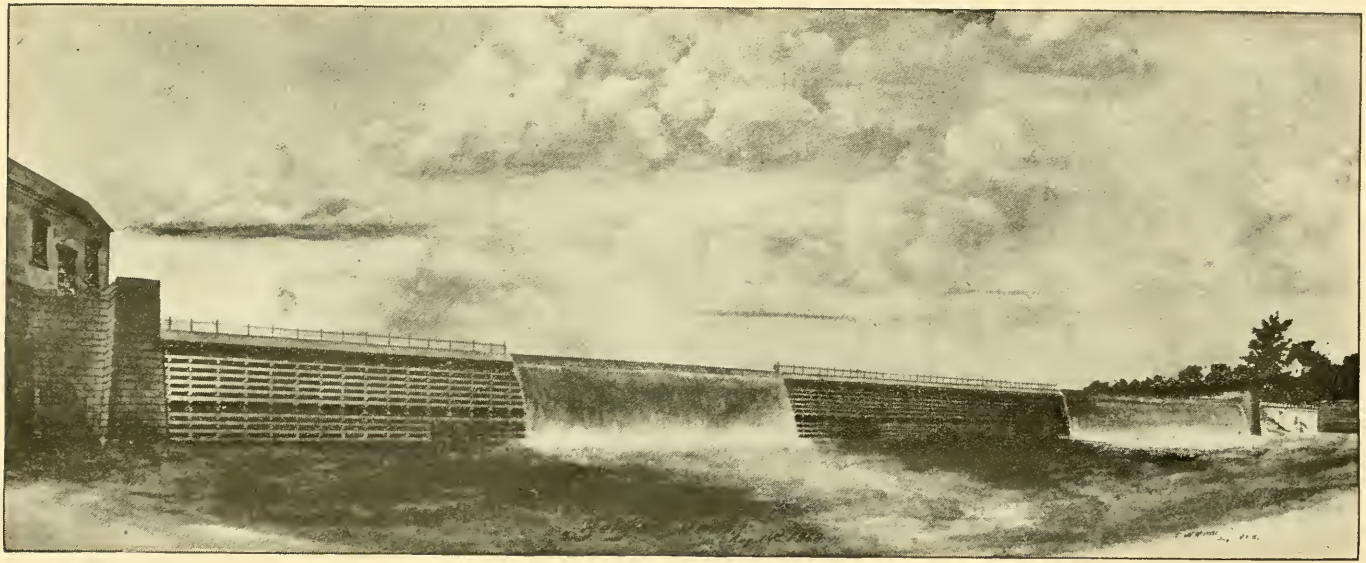

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PLATE LIII.

HERSCHEL
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of the ledge beneath them, these large timbers were, of course, but imperceptibly better than any others would have been. A photograph now in the office of the Holyoke Water Power Company,* of the front face of the dam as it appeared in 1869, makes it look a good deal like a fort after a heavy bombardment. See Plate LIII.

The Apron of the Dam.

There was plainly no time to be lost, and during the years 1868, 1869 and 1870 was built the apron, down-stream from the dam of 1849, and shown with the dam in the cross-section on Plate LIV. As will be seen, its volume far exceeds that of the original dam. It is built of round logs laid up in perpendicular bins, 6 feet square in section, and was filled to the top with stone before it was covered in. The outside covering is of maple, beech and other hard wood—6-inch planks. The lower courses were built afloat, and in sections about 150 feet long. They were fitted, as well as it could be done by a plentiful use of the sounding-rod, to the irregularly-shaped bottom, then sunk by loading with stone. That part of the apron which is above the water level of the pool below the dam was then built as a continuous structure, on top of these lower sections. The lower sections not fitting very closely together, left a series of submerged culverts through the apron, and it was through these culverts that the water spouted out, with great velocity, at a later date, whenever there was any break in the covering of the original dam, as will be spoken of later. In loading the apron with stones, some of them weighing 4 and 5 tons, the stones were brought down the river in scows, and in process of transfer many were dropped into the water, which then struck the back of the dam. Indeed it was no extraordinary performance once in a while to spill a whole scow-load upon the old dam. Once out of sight, these stones were soon out of mind, and so remained until discovered by the divers in 1885. The whole cost of this apron is variously given as $263 000 to $350 000. The effect of the apron has been to prevent further undermining next the heel of the dam, also to support the dam where it was undermined. On the other hand, it speedily caused a new pool to be excavated below the dam, which is again 20 to 25 feet deep at the deepest parts.

During construction of the apron, considerable stone was also filled

* The Hadley Falls Company failed in 1857, and was succeeded by the Holyoke Water Power Company, the present owners, in 1859.

into the old dam. This was done in a rather irregular manner, however, as appeared during the repairs of 1885. Some of the bins were not filled at all, some were filled more than others. As near as I could judge, a slope of 45 degrees from the crest, up-river, might represent the average fill. The whole work was done without the aid of divers to clear for or to set the foundation courses, and was what may be classed as first-class log-driver's work. It was done while the late S. S. Chase, F. Am. Soc. C. E. (died May 29th, 1873) was agent of the Holyoke Water Power Company, and Mr. T. A. Ricker was the foreman in charge.

1870 to 1879.

In this way the dam did its duty until 1879, say ten years more, the crest having, however, been leveled up to the lawful height of the dam, as fixed by the original masonry bench mark, in 1875. This was done by spiking on a new crest timber, and planking down the two slopes up-stream and down-stream with wedge-shape plank, thus making a level crest, but piling on a further thickness of timber at the crest. Ten years later the removal of the crest and of the up-stream portion of these wedge-shaped planks, made no little extra work for the repairs of 1885.

Breaks and Cribs, 1879 to 1885.

One fine morning in 1879 there appeared a very well-defined whirlpool on the surface of the water just above the crest of the dam, and examination soon showed a break through the plank-covering at that point. This and subsequent breaks were repaired by means of cribs sunk so as to inclose the break in the plank-covering of the dam. These cribs were like a box without top or bottom, the under-side of the box cut off on a bevel, which, set on the back of the dam, would bring the upper side horizontal. During the succeeding six years these cribs went through a course of development towards perfection, and increased in size commensurate with the demands of breaks of increasing size, as will presently appear. At one time there was a fleet of six such cribs of various sizes in plan, and of various heights (to fit on the back of the dam at various distances up-stream from the crest), afloat in the pond. The largest crib built is shown on Plate LV, and its construction will need no further explanation.

The break of 1879 was located as shown on the diagram of Plate LVI, and was repaired without especial incident, except such as would

naturally accompany a new experience of that sort. In 1881 there were two more breaks, likewise shown on Plate LVI, which were repaired that year. The presiding genius was a river-driver, who put on also the little patch near the north end of the dam. I may as well mention here, that in 1885 we laid dry this little patch and went under it, inside of the dam. Not finding any of the planks gone underneath the patch, it became interesting to know what that patch had been put on for; but this I have never found out, and must leave it undetermined and a trade secret, as it no doubt was meant to be, by one of the fraternity of river-drivers.

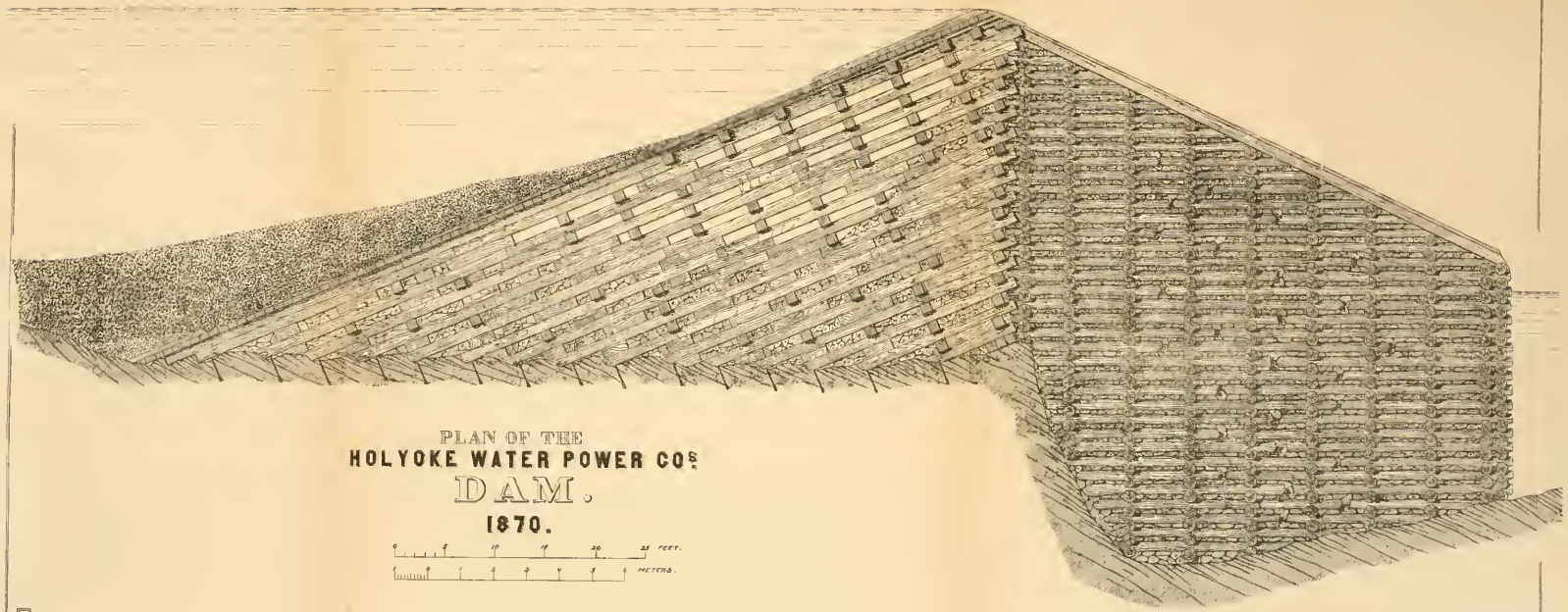
In 1882 the breaks of 1881 again broke through. My own connection with the works commenced in the winter of 1881–82. These two breaks were thoroughly repaired that year, the repairs running along until January or February, 1883, so that the crib from the last break repaired was removed through a channel sawed in the ice. One of the cribs was extended to reach to the crest, and the patch put on included a removal of 20 feet of the crest. The other crib was extended by sinking a sort of bay-window crib outside of the main crib, so as to take in a hole which broke through while we were at work on the original hole. In 1883 there were no breaks, but in 1884 they become worse than ever before. July 19th, 1884, a whirlpool appeared near the center of the dam, the mere central air-hole of which measured about 2 feet in diameter and was nigh 10 feet deep. The gate-keeper insisted that it had sucked in a row-boat which came drifting down the river, a story we always doubted; but in 1885 some pieces of a boat were picked up from out of the interior of the dam, which went far to corroborate the gate-keeper's thrilling tale. The crib used in 1882 was put around the whirlpool, when it was found that the hole had grown meantime, and had extended beyond the capacity of a 20 by 35-foot crib. 4 500 bushel bags of gravel—the gravel sewed up in the bags—dropped into this outside hole, failed to make any impression upon it; the intention having been, to temporarily close or partly close this hole by filling the bin or bins immediately beneath it: then to repair within the crib; then to remove the crib and repair the outside hole. Meantime the supply of water was failing, and it became necessary to resort to other remedies. It was then resolved to build the large crib shown on Plate LV. This crib was commenced August 14th, and built stick by stick as fast as the lumber could be got from the saw-mill. There was no time to draw any

plans or do much designing. It was built for all the world as children build block-houses of play-blocks. It was finished August 28th. Its weight was about 100 tons, and 80 tons of stone were required to sink it on the dam. There having been no opportunity to prepare ways for launching it, it had to be moved as a heavy building is moved, and the shores of the river were soft ground for such work. On the 29th it was moved 14 feet; on the 30th, 4 feet; on the 31st, 4.5 feet; and the hollow island made of spruce timber was got afloat at 1.40 o'clock (*not* 13.40 o'clock) of September 2d. That day it was set on the dam, making 19 days from the time it was commenced until it was in place. To encourage other engineers engaged in similar work, I may say in passing, that these 19 days were lived through under the expressed displeasure and dissatisfaction of about all the people for whose very benefit this work was being done. To think back upon what was said at the time, we who did the work would think that we had been at least three months about it; but the record shows only 19 days, and I doubt if any one is left who does not now think that the whole operation was highly commendable in all who took any part in it.

It may be well to speak, in this connection, concerning the details of the sinking of and operations within such a crib, as finally settled upon.

Work With and Within the Cribs.

The crib being hauled out into the stream was allowed to float down-stream, and so as to fence in the whirlpool, by carefully paying out on a strongly anchored line. At this time there would be a heavy pressure on the up-stream face of the crib, this face being much larger in area (owing to the slope of the dam) than the opposite down-stream face. Stones were then scowed out and dropped into the pockets of the crib at each end. When the crib took the ground it would do so by a sudden movement, and, owing to the excess of pressure on the up-stream face, the crib would take the ground down-stream from a point vertically beneath it when afloat. It was therefore necessary to allow for this, and to keep the crib 6 to 10 feet up-stream, while afloat, from where it was to stand on the dam. Sometimes timber-cleats were spiked to the crest of the dam to prevent the crib from getting too near the crest; for once aground, and not in the right place, the unloading and moving of such a craft would have been difficult, time-taking and expensive. If the break was near the crest, so that the crib could stand on the plank-


PLAN OF THE
HOLYOKE WATER POWER CO.S
DAM.
1870.
0 5 10 15 20 25 FEET.
METERS.

covering of the dam, the subsequent work was comparatively easy; but if the crib had to land partly or wholly on the gravel and boulders covering the dam up to 40 or more feet upstream from the crest, there remained considerable work yet to do to carry the crib, sometimes nigh 15 feet through this deposit, to a junction with the dam beneath. In 1885 I tried the water-jet to effect this, but with only partial success, for the reason that some of the intervening deposit consisted of heavy 2, 3 and 4 ton boulders, water-logged logs, and similar heavy material. The orthodox way, and the only way I yet know of, that is feasible, was to calmly proceed to drive sheet piling all about the crib. Then, when the current under the crib had become sufficiently accelerated and concentrated, to drive out from underneath the edge of the crib any boulder that might have lodged there, the crib would settle; the sheet-piling plank already driven, being prevented from settling with the crib, would strip off, and proceed to lay themselves fan-shape upon the surface of the water, whence most of them could be picked up and driven again. In this way the sheet piling for the 1885 crib, which is the one sunk through a thicker mass of deposit than any of the others, was driven six times before the crib could be brought to a good bearing on the dam. The crib once on the dam, the joint between the sheet piling and the dam was made tight by dumping in bags of gravel. These were second-hand bags of gunny or other coarse cloth, costing usually about 5 cents each. The gravel was sewed up in them and the bags dumped in, some loose gravel being added from time to time. Clay is generally used in the same manner, but for what reason I have never been able to discover. It is more difficult to handle and melts out of the bags to a material extent on being thrown into the water. I have always used clean gravel and strongly recommend it. In the way described, a water-tight joint would gradually be made between the crib and the dam. This accomplished, the rest of the work would be comparatively easy. The water inside the crib would speedily run out through the hole in the dam, and the rest of the work would consist of ordinary dam repairs and of unloading the crib and floating it ashore.

Making of New Holes in Mending an Old One.

One great objection attendant upon this method of making the repairs, was the lodging of the crib (weighing, with its load of stone, up to 125 or 150 tons when half empty of water) on top of a boulder

or hard log. This would have a tendency to break another hole through the dam, and in point of fact, in three cases out of the four under my charge, one or more such additional holes were punched through during the process of sinking the first crib. The dam being hollow, every hole through the covering would be followed by a large loss of water. In 1884 the hole finally measured about 60 feet by 2 or 3 feet, which put under 10 to 15 feet head, will be found to pass no inconsiderable stream of water. The effect of the apron was to dam back this water fully 20 feet, or to within 10 feet of the crest of the dam, and the water escaped through the joints between the several sections of the foundation pieces of the apron, as above described. The water inside the dam could never be brought down lower than about grade 80 (top of the crest is 100), so that the contingency of a break below grade 80 was an ugly feature to look forward to.

But to resume concerning the operations of 1884. By the time the large crib, 40 feet by 45 feet, made to just take in the break in the dam when it was begun, had been set on the dam (the 20 by 35-foot crib having previously been removed) it was found that the hole had again grown, and reached beyond even this big crib. No lee-way could have been allowed in size of crib, because the pond would not have floated a larger crib than 40 feet by 45 feet, drawing 15 feet, nor would it have been otherwise advisable, as I now view the case. 40 feet by 45 feet will be found sufficiently unwieldy for ordinary work. To meet the emergency of the case, the 20 by 35-foot crib was therefore sunk alongside of the big crib, as shown on the diagram. This passed off without accident; the two cribs combined sufficed to cover the hole in the covering of the dam; and September 20th, noon, the big hole of 1884 was a thing of the past.

Autumn of 1884.

The proper course to pursue for the future became now a subject for most anxious consideration. The dam being all of the same age, there was no particular reason why the next hole, instead of measuring 60 by 4, should not measure 300 by 10, or any other dimensions (speaking after the manner of the integral calculus), within the limits of 1 017 by 92, the up-stream surface of the dam, and thus let out all the water of the river, and stop the mills, with an invested capital of $12 000 000, even if it did not destroy the whole dam. Again, those who had had a taste

of what it meant to fight the Connecticut River under the circumstances which have been described, had no particular liking towards a renewal of the contest. Personally I considered it a piece of good luck that we had been able to stop the 1884 break without first breaking in another large hole, and another, and another, and so on.

Some months after removing the 1884 cribs, there were indications of a large leak next below the patch of 1884, which did, in July, 1885, blossom out into the troublesome break of that year, in 28 feet of water and river deposit; but that was then in the undeveloped future. And I considered the covering of the dam in that condition, that I thought the usual 8 or 9 feet freshet in the approaching spring of the year would certainly cause incalculable disaster. All arguments in favor of proceeding to the construction of a stone dam, a work which would have required not less than three, and probably all of or more than four years, fell upon deaf ears, therefore, as far as I was concerned (from proper motives of policy they were also addressed to a person largely dumb); and with the support of the executive officers and of the directors of the company, preparations were immediately begun for a thorough strengthening of the old dam. But the discussions lasted long enough to lead to the designing of and experiments with the various forms of dams, to be built of stone, of which mention will be made later.

First Attempt at a Prevention of Future "Breaks."

The object sought to be accomplished was to prevent further breaks through the covering of the dam, and the project at first took the shape of endeavoring to sink cribs on the dam above the gravel line; to cut holes through the covering, dump in gravel, and wash it, or hydraulic it in, by letting water into the crib and upon the gravel. The idea was to give the dam a "subcutaneous injection of gravel." It was deemed advisable to make the attempt to do this work in the fall and winter of 1884, so as to have it done before the spring freshets. The big crib was therefore allowed to remain on the dam. Railroad tracks were built; a derrick and hoisting-engine provided; an Osgood dredge was built without the second chain or a dredge-bucket, to act as a floating derrick in handling the dump-buckets; 120 dump-buckets, and scows to float them, were built; electric lights provided, and Sunday, December 7th, the first 67 buckets of gravel were dumped into the dam. December 12th, 13th and 15th, 552 more buckets followed, when it became neces-

sary to abandon the work for the winter. What with the difficulty of keeping open a channel for the gravel scows, the freezing of the gravel in the buckets, and, worst of all, the accumulations of ice inside of the cribs, no progress could be made. The big crib was removed through a channel sawed through the ice, and the work came to a standstill until after the spring freshets. These fall to 2 feet on the dam at dates ranging from about June 1st to July 1st, which was not a pleasant outlook for parties anxious to commence work on a weak dam.

Winter of 1884–85—Studies for the Work to be Done.

Meantime, however, opportunity was offered for further careful study of the whole subject. A model of the dam and apron was made, $\frac{1}{48}$ full size, and embodying all that was known of the construction of the same at that date.

As this is written in an unconstrained, discoursive manner, I do not hesitate to speak at this point upon the great advantages to be derived by engineers from a study of models of a projected work. This is one of those things not taught in the academies, and many an engineer goes through his professional life unappreciative of, or disdaining the aid of, these most helpful, yet unassuming, instruments for stimulating his inventive powers. And yet we have very high and, in the profession, ancient authority for such methods. John Smeaton, the builder of the Eddystone light-house, was the first man who, in English-speaking countries, called himself a civil engineer. Before setting about the construction of the Eddystone light-house, he made, as is well known, a model, to scale, with his own hands, of the structure and of all the principal, if not of every stone in it. Many of the old masters in engineering were equally proficient in the use of tools, and believed in the teaching of models. It is to be hoped that the modern shop-practice form of education will enure to the benefit of the rising generation of civil engineers in this very manner. It may, indeed, give the model a social standing in every respect the equal of that now held by the drawing, and, this accomplished, its value in certain cases will be speedily seen to be far superior to that of the drawing. Without the education that comes from handling things—with all the work done under contract and by contractors—it has sometimes seemed to me that the profession was rapidly degenerating into the position of cloistered, closet students, or else of a high grade of "clerk of the works," and that none should more

favor the new education, which, as has been tersely put, "educates the whole boy, not half of him," than civil engineers. As far as my experience goes, I am free to admit that I have spent more time during the last six years in the carpenter-shop and on the works than I have at the desk or at the drawing-table, and a little more than the customary amount of this sort of experience would, I am convinced, benefit the work of any engineer.

It was while poring over the model of the dam spoken of, that my friend, Hamilton Smith, Jr., M. Am. Soc. C. E., suggested the idea of putting in a row of sheet piling, resting against a line of timbers of the dam, not perpendicularly, which would not have been practicable, but overhanging and at right angles to the covering of the dam, as was afterwards done; and, following up this idea, the whole scheme of the work was changed, from working inside of cribs, to the use of floating coffer-dams, which should reach to the crest of the dam, and lay dry a strip next the crest 20 feet wide and 100 feet long at a time. The coffers and end-piece finally used are shown on Plates LVII and LVIII, and the diagram on Plate LVI shows how the coffers and end-pieces were set on the dam.

Plan Adopted.

The whole plan as adopted, and in the main carried out, was as follows:

To set two coffers on the dam, making 100 feet of coffer, then shut off the ends, either by an end-piece, or by one of the abutments. Then set two more coffers outside of the forward end-piece, and another end-piece forward of these. Finally, take up the rear end-piece and two coffers, and set them forward of those last set, and so on. The end-pieces which were 20 feet wide would, in this way, alternately act as a water stop with one side and then with the other, according as each one came to be in the front and would next be left in the rear. To set them on the dam and make a water-tight joint, it was evident that the old method of sheet piling and bags could no longer be used, and it was determined to have divers clear off the dam, and make the joints by submarine carpentering. Once set, the water inside the coffers would speedily run out through the leaky dam; the covering for 20 feet down from the crest could then be stripped off, the sheet piling put in, gravel dumped either side of it, and washed down, or profusely puddled, until no more could be got in. The next step would be to restore the covering of the dam and go on to the next section.

Beginning of the Work, May 29th, 1885.

With this general plan in view, and a profound appreciation of our ignorance of what was about to be encountered, both within and on the surface of the old dam, a diver was sent down May 29th, 1885, to clear the dam for the first coffer. It must be remembered here, that the only knowledge which had then been gained of the construction or condition of the dam, came from the limited views had of it and experience gained in course of the repairs with cribs. These frequently did not agree with old newspaper accounts, or with memory or tradition, so that considerable uncertainty existed on essential points. No great amount of stone was ever found inside the dam. This may now be readily explained by saying that the current through the break in the covering of the dam had washed them out. On the other hand there was always a good deal of gravel at the bottom of the river under the dam, which it is now plain, but was not then, had been deposited there during the gradual dieing out of the current, as the joints between the crib and dam had been made tight. No large stones were ever found on the dam, because, as is now clear, they had dropped through. Indeed, I feel strongly, that large stones of this sort dropped on the planking in 1868 and 1870, may have been the prime cause of several of the original breaks; and, if so, they would of course have been the very first thing to drop through, when the plank, on further weakening by age, finally and entirely gave way. But at the time, as said, the whole work was as yet in the nature of an untried experiment, with doubters of its success and opponents of the whole thing by the score; with active supporters of the executive officers of the company in their responsible and arduous position but few in number.

Clearing the Dam for the Coffers.

It soon became apparent that there was much more gravel debris and river deposit on the dam, than the soundings taken every 20 feet across, and at 5 feet distances up-stream, had indicated, or that the diver's capabilities in removing deposit, had been overrated. The plan had been to let him wash off the dam with a stream at 80 or 90 pounds pressure through an inch nozzle. But this alone would not do. A large and weighted hoe, worked from floats; cutting 9 by 9-inch holes through the covering of the dam, were tried in turn, without much success, though finally a small space, afterwards utilized for the site of end-piece No. 1

PLATE LV
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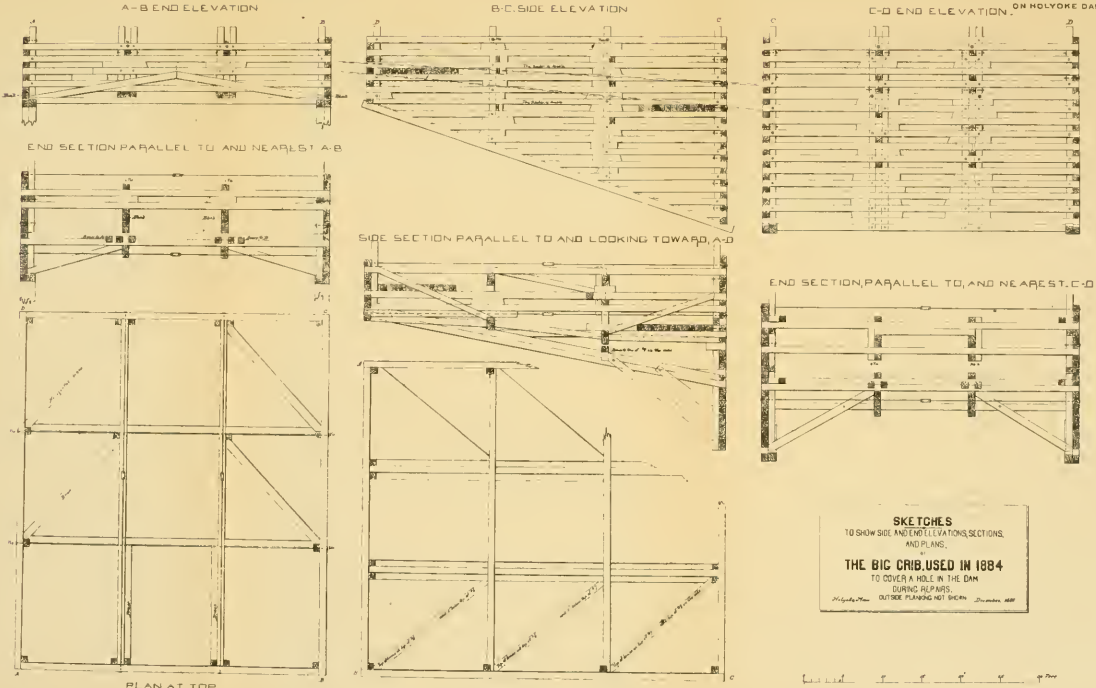

(indicated on the diagram), was cleared off in this way. To get an insight into the work about to be done, and to make a start, end-piece No. 1 was sunk as stated; the water let out of it, the planking of the dam removed. the stone found in the bins taken out by hand, and the sheet piling put in for a width of two bins. Plainly the success of the whole work depended on accelerating the work of the divers, for, from the start, it had been recognized that the whole work would have to be done in 4—at most 4½—months, or probably fail. And all efforts were now turned in that direction.

Submarine Road-Scraper.

The next experiment was with an ordinary road-scraper, hauled down the slope of the dam under guidance of a diver, by a hoisting-engine mounted on an anchored scow, and pulled back again by the same engine, by means of a line and snatch-block, the latter fastened to the crest of the dam. This plan worked fairly well, and two divers and crew (tenders and pumpers), with two men on the scow, cleared off 50 feet in five days, or, at that rate, 205 days for the whole dam; therefore, still too slow. This speed could, of course, have been doubled, by starting in another such crew, but the greatest objection came from the danger to the divers inherent to this method. The diver had to walk along behind the scraper and keep heaping up the material in a windrow at the end of his route. And it will bring home to the reader a realizing sense of the responsibility of the situation, when it is pointed out that, in the opinion of the engineer, there was constant danger that this extra weight would break through the dam, and in that event no doubt kill the diver, besides flooding the whole work. It was literally treading about on egg-shells—a constant exercise of all attainable caution, and yet striving to push on the work. The freshet in the spring of 1885 had been only 6½ feet on the dam, instead of 9 feet or more, as usual, and to that extent the dam had again been tried, but it was not to be thoroughly trusted in any portion of the covering. And it was well that it was not trusted. Later on, the divers were obliged several times to floor over portions of the dam before they dared to walk or roll stones about on it. Especially did it become necessary to board over leaks, which sucked in the air-hose and were otherwise annoying and dangerous.

Dredge to Clean the Dam.

The plan decided on was to convert the Osgood floating derrick into a very small (half-yard) clam-shell dredge, then let both (finally three divers) play on the gravel until a windrow had been formed, then let the dredge remove it. To save time, the dredge had orders to work early in the morning, noon-times and nights, and under no consideration to let the bucket come down hard. This made the work of the divers comparatively safe, for they heaped up the material ahead of them but little, and where the dredge had been at work it was reasonable to assume that a 30 to 40-pound diver could walk about. This plan proved very successful and completed the work. On the diagram Plate LVI, will be found the dates when the divers commenced and finished cleaning the different sections; when the road-scraper and when the dredge commenced; when the several end-pieces and coffers were set, the sections laid dry, gravel filling put in, and other information. The dredge built to swing buckets of gravel into the dam, in point of fact never swung a bucket in 1885; but as a dust-pan for the divers' sweeping she became "worth her weight in gold," as they put it; besides which, she could in fifteen minutes be stripped of her bucket and serve as a floating derrick to hoist up big stones, chained on by the divers, or to set the coffers, or to pull them off again. As she did her part to save the whole concern from shipwreck, she was not inappropriately named the Grace Darling, and served faithfully to the end. Three divers to operate three nozzles and fire streams, and the dredge, finally cleared 120 feet of dam in about four days, sometimes removing from that length of dam, five or six scow-loads of big stone. The divers also made tight all the joints between the coffers and end-pieces, and between these and the dam, and generally were indispensable for a rapid, or for a practicable, prosecution of the work.

Loss of Two Divers.

While on this subject, something more may be said as to divers and their work. Barring sprains and bruises, also one leg broken, the loss of two divers were the only accidents among 125 men, working over four months on this somewhat hazardous undertaking. The first diver lost, went over the dam, Monday, June 8th. Several weeks later, and after they had got away, his mates confessed that he had drunk himself into a comatose condition the night before, and had been remonstrated with,

not to go to work that morning, as being not yet over his drunk. And this much being stated, no further explanation is necessary. These circumstances did not, however, prevent his mates from going about with a hang-dog air, and as though the accident had been the fault of the work, too dangerous, and all that, and they actually succeeded in stopping the whole work for about a day and a half. The discharge of the whole gang and a commencement with an entirely new set was necessary to put things to rights again. In going over the dam, the diver was stopped on the apron by his life line, though the air-hose coupling pulled out. Afterwards, through some bungling, he was allowed to slide into the pool at the foot of the apron. He was got ashore in just five minutes from the time the hose parted, with a physician, summoned by telephone, there to receive him, but the man was then dead.

Gross' Negligence in the Manner of Constructing Divers' Armor.

I will now state the details of another accident to a diver, and am thus enabled, by the contrast of results, to call the attention of the profession to a gross piece of negligence, as I have long viewed it, practiced by makers of divers' gear in this country. But the first-named accident enabled me to nullify such imperfection of armor, at least within the range of my own influence, after I had been faithfully working to that end for nigh twenty years. October 27th, 1885, John P. Mitchell, who had worked longest on the Holyoke dam, was down in 90 feet of water in the hold of a vessel sunk off Baker's Island, Salem Harbor, Mass., when a portion of the air-chamber of the air-pump blew out without attracting the attention of those on the divers' schooner. This naturally deprived Mitchell of all supply of air. He signalled for more air twice (this is done on the air-hose), but his signals were not noticed for some reason unknown. He felt a bursting pressure about his head (I felt a little of this myself in an experiment to be detailed later), then lost all consciousness. On the other hand, the tender not hearing from his diver for some time, signaled him twice on the life line to learn whether he was all right, and getting no response Mitchell was hauled up. He was entirely senseless when laid on deck, but came to after a little while, and the next day was apparently none the worse for his experience of the previous day. To explain the contrast, it is necessary to call attention to the one radical defect in all divers' gear as made in this country, which is the absence of a check-valve next the helmet, where

the air-hose enters. This struck me as a piece of negligence, or what should be considered negligence, the first time I saw a diver's gear, in 1866. I often spoke of it, and some eight or ten years later, read in a book, that in England a check-valve is always put in. Nevertheless, and in spite of lives being continually lost for the want of it, I could make no impression on divers and others about it. But after the death of the diver first above spoken of, and in telegraphing his loss, I added: "I insist on check valves being put on," which had the desired effect. The party furnishing divers immediately had them put on all his eight helmets; without such a check-valve Mitchell would certainly have been a dead man the moment the air chamber broke; and they have in other ways amply shown their value during the test of a season's service. Indeed, divers now lay immunity from certain accidents to them which should be credited elsewhere. Experiment has also shown that a diver could stay three minutes in 15 feet of water without any supply of air from the pump, and without material annoyance. He merely got tired of waiting, signaled for air, and went on with his work. Two and one-half minutes is all I wanted of it, however, sitting on deck with a watch in my hand. If now the profession will sternly set their faces against any diver going down on work under their charge unless the helmet be provided with the check-valve spoken of, I am satisfied that the great majority of losses of life among divers will have been prevented. And makers of diving helmets in this country should be made to understand that the making and offering for sale of a diver's helmet without a check valve on the air inlet is criminal malpractice. Another thing that should be insisted on is the use of a telephone between tender and diver.* The wires to be coiled about the hose to the pump, thence led to the tender; and the tender to wear a telephonic helmet after the manner of operators at the "Central Office." I believe that these improvements would lead to the more general employment of divers on engineering works, and this again would enure largely, I am convinced, to the benefit of many classes of such work.†

The second diver lost at Holyoke, in 1885, was Mr. Thos. W. Conklin, of New York, who had been a diver over forty years. (*Harper's Weekly* of August 22d, 1885, contains a fair portrait of Mr. Conklin.) His death is not chargeable to the regular work of preserving the dam

* See paper on Submarine Telephony, by Charles Ward Raymond, M. Am. Soc. C. E., Transactions of the Society, Vol. VII, No. 173, October, 1878.

† Since this was written, the Bell Telephone Company has devised a telephonic apparatus for the use of divers.

PLATE LVI.
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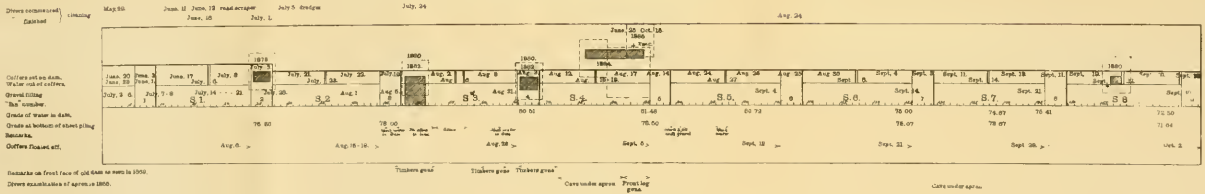
ON HOLYOKE DAM



Remarks on front face of old dam as seen in 1859.
Divers examination of apron in 1885.

DIAGRAM
Showing work done on dam in 1885
Holyoke, Mass. January, 1886

here described, but occurred in working on the "crib" sunk in 1885, about the "break" of that year. After the crib had settled to a junction with the dam, the sheet piling having been driven six times, as above mentioned, it was thought worth while to attempt to save weight on the dam, by placing the bags of gravel by hand, rather than by dumping them in. The divers were instructed to lower themselves upon the covering of the dam, some 40 feet from the crib, on the solid patch of 1884, that afternoon; thence they were to have carefully felt their way towards the crib, and report. Mr. Conklin said he knew all about guarding himself against currents; he would crawl forward on his hands and knees, feeling for currents with one hand ahead of him. Notwithstanding these precautionary measures, the two divers, Conklin and Mitchell, rowed their scow straight out to the crib, in less than an hour after the above conversation, made fast to the crib, and immediately lowered themselves down a rope, the one directly into a hole in the dam, under 20 feet head of water, whose existence was not known, since which time nothing has been seen of him to this day. Mitchell, the other diver, was called up to see what was the matter with Mr. Conklin. He followed Conklin's line down, but checked himself on getting into the current, and was hauled up. By no power put on Conklin's lines in all conceivable directions, finally with a capstan, could they be made to yield in the slightest. The body was probably wedged far in among the timbers of the dam, and later search also failing to reach it, it is now buried in gravel near the exact center of the dam. Of course, it is easy to say that if the divers wanted to go at this examination by themselves, they should have felt first with a sounding-pole, or that they should have gone down a ladder, or done as was agreed upon but a short time previously. The use of a ladder, which seems so natural in the open air, is strangely fought shy of by divers, but should be insisted upon, in all cases of doubt.

Employment of Divers.

When it was first contemplated to employ divers, the two propositions, one to buy gear, and train some of our men to be divers, and the other, to contract for the furnishing of divers with gear, were fully discussed, and the second method was deemed the wisest and least liable to lead to loss of life or to consequent claims for damages. However that may have been, certain it is that none of our men would ever have been

lost in either of the ways in which the two divers met their death. No one who has ever worked on a dam like the Holyoke dam would think of purposely and needlessly crawling up to an opening in the flash-boards, with 3 feet of water passing through and over the dam, and thus be carried over, no matter how drunk he was. Nor would any one who had worked on any of the cribs ever have gone down alongside of one, except after making all possible preliminary examination. And such men would have heeded the advice and warnings, in each case given but a short time previously, against the very accidents that occurred. On the other hand, accidents and loss of life might have occurred in teaching the men to work in diver's armor. I leave the matter an open question for the future, though I think that any ordinarily intelligent workman should have little difficulty in learning to work at his trade under water; and with only a little time to spare, one may undertake to teach the art of both tending and diving to proper parties.

Coffers and End-Pieces.

The coffers and end-pieces were built on a platform wharf, and launched on ways into the water. When new, and loaded with stone, as shown in the drawing, a 50-foot coffer would float with the boarded side just about parallel to the surface of the water. Later on, when water-logged, they would float point down, until the stones were taken out, when they could again be made to float flat side up. The stone ballast was taken out, sometimes by the divers with the coffers afloat, sometimes by hand while the coffers were yet set on the dam. The first coffer and end-pieces built were 6 feet longer on the base than those shown in the drawings, and provided for a 4-foot freshet. It was afterwards deemed advisable to allow an increase of danger from freshets, by making the coffers narrower on the base and lower, but at the same time diminishing the danger from freshets, by being thereby enabled to do the whole work quicker. The two kinds of coffer and end-piece used, are shown on the diagram. As it afterwards turned out, the month of August, 1885, was the wettest August since 1856. It contained three freshets, including one of 4½ feet, which could barely be controlled by temporary flash-boards hastily put on. As one of the amenities of this sort of operations, it may be noted that 6 inches more of water would undoubtedly have flooded the whole work and the interior of the old dam. These coffers were a great success, and I again lay no small portion of this to

the use of models. A model of the coffers floated in a tub, showed their probable behavior in the mill-pond, which afterwards was perfectly realized. From being so evenly balanced when afloat, that either the open end, or top or bottom, would remain on top nearly equally well, the handling of the coffers and setting them on the dam, or taking them off again, became a matter of small concern. With the aid of the floating derrick, two coffers could readily be set on the dam in one day.

The end-pieces were, of course, more stable, and were simply floated in, hauled up and loaded. Two days' work of three divers would make all the joints tight, and everything was then ready to get the water out. One of the coffers had two gates, 4 feet square, cut in it, to supply the leakage of the inclosed portion of the dam. Without such gates, the water would fall a foot lower inside than out, and be apt to get the coffers out of line, before they were entirely loaded. Getting the water out was always an interesting operation. The forward end-piece had to be braced where it set on the crest of the dam, and this could not well be done until the water was down 2 or 3 feet. But everything could be got ready for it; then at a signal, the two gates would be hammered down, and within one hour from the signal, the slimy surface of the dam would be washed off with the diver's fire-stream hose, and eighty men would be at work inside, tearing up the old covering of the dam.

Unloading and moving the coffers was an anxious operation until it had been done once. The system adopted is shown on the photographic views. Timbers 12 by 12 inches were laid from the edge of the coffers, to the crest of the dam. On these were placed 3-inch planks, and the stone load of the coffers was then handed up, and piled on these planks. When all the stone had been thus got out (in some of the coffers from under 2 or 3 feet of water), the coffers, and section they inclosed, were allowed to fill with water, through the gates above mentioned. Then the stones were removed from off the plank, and generally used to set another pair of coffers further forward. Finally the plank and timbers were taken off. Most of the coffers remained on the dam when the work of removing them was at this stage, the planking over the joints, and to or against the end-pieces, being just sufficient to hold all in place. They were then hauled off by a capstan boat, or lifted off by the floating derrick. Sometimes they would roll off like huge porpoises, the moment the least pry was exerted to start them. The triangular shape of the coffers proved very advantageous for a floating coffer-dam, and

can be warmly recommended. Some of the coffers and end-pieces were used three times, and were good, apparently, for many more rounds of service.

Sheet-Piling.

Without a model it is almost impossible to show clearly how a row of sheet-piling put against one face of one row of the bins, can make a tight water-stop throughout the crib-work of the dam. Suffice to say that it does. The bins were dug out, or the stone picked out by hand, as low as the water inside the dam would permit in every case, the men sometimes working in water up to their chins as they stooped down to pick up a stone with one hand. The diagram gives some measured grades of bottom of the sheet-piling. Throughout the dam this bottom was several feet below the old stone-filling, plainly to be recognized during this work, which had been put in in 1849. The sheet-piling was driven into this filling about a foot, all the plank reaching the width of one "bin," being driven at a time. But beyond this much driving, the planks were set as carefully by hand as any floor is laid, and were well braced against the opposite face of the "bin." Taken as a whole, and together with the frame-work of the dam that penetrates them, they constitute a close structure of 3-inch plank, some tongued and grooved, some only jointed, from one abutment to the other, and reaching down 25 to 28 feet below the crest of the dam.

Gravel Filling.

Each side of the sheet-piling is a mass of puddled gravel, measuring about 12 900 cubic yards altogether, being all that the dam would take when washed in with an ample supply of water. No part of the work gave less anxiety and more satisfaction than this, from the day it was started. And no part had been called in question to a greater extent, especially the "hydraulicing" feature of it, before the work was begun. Possibly these doubts expressed were the very instruments which caused the gravel service to be so well organized, and made it that part of the work which was constantly spurring the other parts to increased exertions and to increased speed. The gravel pit was about two miles up-river. A branch track to the Connecticut River Railroad, and a double track built on trestles next the same road, where it passes the head gate-house, furnished railroad connection. A double-drum hoisting-engine and derrick with wire-rope fall, served as a transfer from the cars to scows.

PLATE LVII
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HERSCHEL
ON HOLYOKE DAM

PLAN

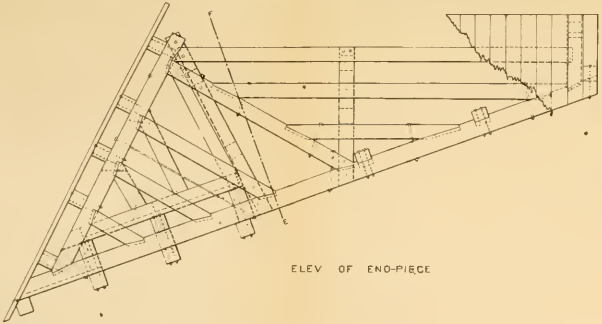
SHOWING CONSTRUCTION

OF

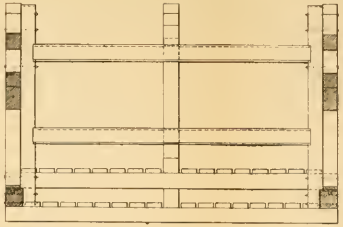
END-PIECE AND COFFER DAM

USED IN REPAIRS ON DAM AT HOLYOKE

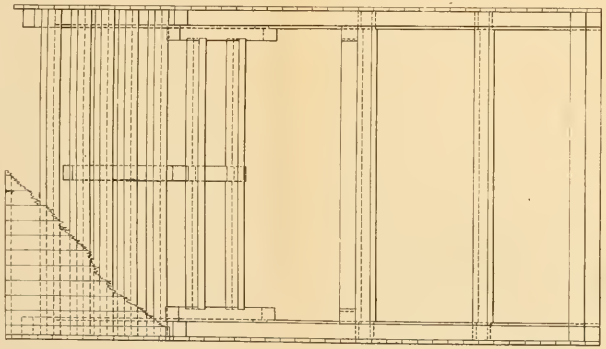
SUMMER OF 1885



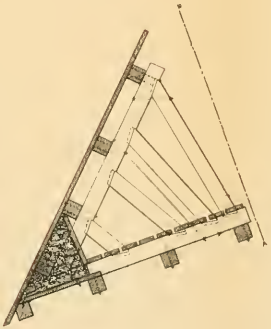
ELEV OF END-PIECE



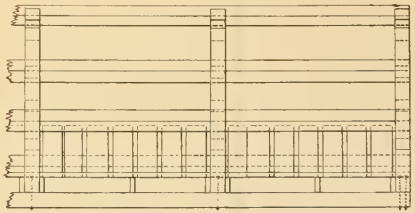
SECTION ON E F



PLAN OF END-PIECE



SECTION OF COFFER



FRONT ELEV. ON A B

Float stages, 3 logs wide, served as a tow-path out to the work. A derrick on the work completed the machinery for handling or transporting the material. The gravel was loaded at the pit into dump buckets, 12 buckets just covering a flat-car. This meant 15 shovelers and a foreman. Two cars or 24 buckets made a train load. Three trains were constantly in service: one in the pit, one on the way, and one being unloaded by the shore derrick. This meant one engine-driver, fireman, and two brakemen. Three scows, holding 12 boxes each, constantly in service on the river: one being loaded, one on the way out, and one being unloaded by the derrick out on the work. This meant two men and two boys at hoisting engines, six men at shore derrick and scow, nine men hauling, baling and unloading scows, and one man to dump the buckets. In this way the gravel which was shoveled into a bucket in the pit was finally dumped from the same bucket where wanted in the dam. This required 108 dump buckets, or with an allowance for details to the hospital, 116 buckets. I give drawings showing one of these buckets. As an implement long in use in Holyoke, and by a process of practical evolution become a veritable "one-horse shay," no more likely to break in one part than in any other, let it not be passed by in disdain. They cost about $25 each, made of oak plank. See Plate LIX.

The controlling element in the line from the pit to the dam, as to speed, was the steam derrick on shore. As it had to pick up an empty bucket off the scow, then leave this on a car, be hooked to a full bucket and leave this on a scow, the extra hooking and unhooking of buckets put this derrick at a disadvantage with the derrick out on the work; which merely picked up a full bucket, swung it, had the bucket dumped, and retaining hold of it, swung it back on to the scow. The gravel service commenced July 2d, with 96 buckets put in that day; next day 159. By July 20th, 192 buckets had become the regular day's work, with one spurt of 204 buckets. By August 13th this had been increased to 240 buckets, and on the 23d, "Mose" beat the record with 264 buckets. But better work was yet to come. On giving them a "stent" of 328 buckets, August 29th, they had them all in by 4 P.M., upon which we kept right along (under extra pay) till 8 P.M., and put in 417 buckets that day. Finally, the record was beaten twice more with 372, and last with 395 buckets, up to 6 P.M., or in 10 hours: and 539 buckets in 13¾ hours, (39.2 buckets per hour) was the maximum day's work.

Put in at the rate of 360 buckets per day of 10 hours, it cost 32½ cents per cubic yard for wages (reckoning the bucket at 0.8 cubic yard) of which about 10 cents would be for railroad service, we furnishing our own brakemen and switch attendants. To this should be added cost of machinery required, or a percentage on same, and coal bill for two hoisting engines. Reckoning for the whole work of 1885, and including rainy days, windy days and other interruptions, the gravel went in at the rate of 254 buckets per 10 hours of days on which the gravel trains ran. Put in at the rate of 250 buckets per day of 10 hours, it would cost for wages 46.6 cents per cubic yard, with about 15 cents of this for railroad service.

"HYDRAULICING."

It was important that the gravel should be made to reach as far into the dam as possible. The back of the dam being quite steep (about 2.9 on 1), it was evident that hydraulicing operations down the slope would be prosecuted under favorable circumstances.

A little reflection also showed that for purposes of washing a loose dump down hill, water from a state of rest would be nearly as good as water issuing forth with great velocity. We therefore used three lines of hose, tapped into the coffer-dam—an ample and cheap source of supply. Indeed, as it often seemed to the nigh-distracted chief engineer, the ready supply of water for hydraulicing purposes was the one advantage which could be set off against the many disadvantages appurtenant to working below the water level and out in the middle of the Connecticut River. Ordinarily the supply from the three lines of hose was supplemented, at the foot of the visible slope, within the coffer-dam, by a stream of water, let in, by pulling off a top plank somewhere; and along down the invisible slope, in the interior of the dam, and outside of the coffers, or directly beneath them, this joint supply of water for hydraulicing, was further supplemented, by the leakage of the dam, raining down upon the moving gravel mush, in perfect sheets. The old planks of the dam were water-worn at the edges, so that a spade could be stuck down through the seams in most any part of the dam. As a result of all this, the gravel and water poured into every crack and crevice, not to mention large void of the dam, in a very satisfactory manner. The amount put in, varied from 13 to 20 buckets per lineal foot of dam. With the 619 buckets put in in 1884, there were dumped and hydrauliced into the dam in all 18 121 buckets, which I estimate at

PLATE LVIII
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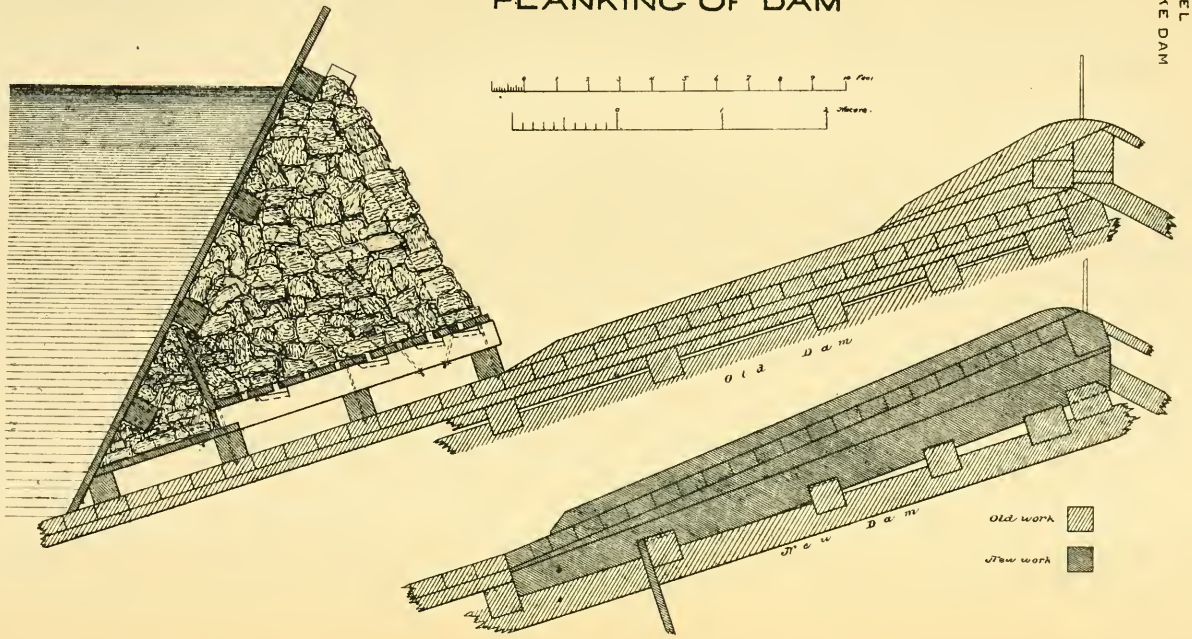
ON HOLYOKE DAM

PLAN
SHOWING
SECTION OF COFFER
AND OF
PLANKING OF DAM



Sept. 8th 1886

12 896.8 cubic yards. Assuming that the dam was filled 10 feet deep with stone in 1849, and estimating the filling of 1868-70 as equal to a slope up-stream from the crest of 45 degrees, which is the best estimate I could make, and taking out the volume of the timbers of the framing of the dam, I estimated from these data that it would take 11 300 cubic yards of gravel to fill all the voids. I am therefore satisfied that but little space devoid of gravel, stone or timber is now left within the dam. Such as there is, is of course, now full of water, which would in this way prevent any great pressure again coming upon the old planking, and would prevent what we have called a break. This, the primary object of the whole work, may therefore be considered to have been satisfactorily attained.

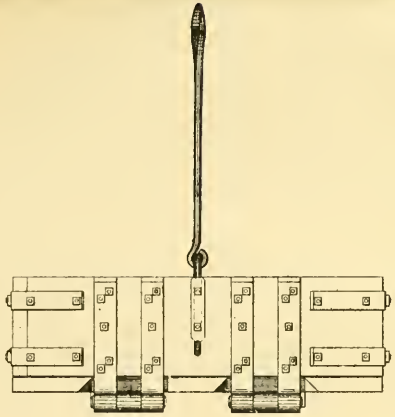
Any Further "Breaks" Impossible, or of No Consequence.

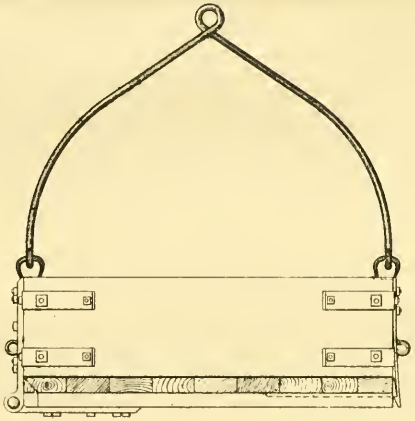
The hole in the covering, through which the diver, Mr. Conklin, was drawn into the interior of the dam and killed, was not planked over. To avoid sinking another crib about it, it was plugged up by spiking plank after plank, let into this hole, first to the outside of the crib of 1885, then to the plank thus spiked on, and so on, until a solid timber plug, reaching, of course, above water, and measuring about 4 feet by 6 feet, had been thus constructed. Bags of gravel dumped in about this plug and the crib, soon made a water-tight joint, but as the water inside the dam could never be brought down below grade 80, the hole inside the crib had to be planked over by divers. After the work on the dam herein described was done, the gravel bags about the "plug" were removed by dredging, the plug was pulled to pieces again, and a diver went down a ladder and into this very hole. There was then no suction, naturally, and beyond being of historical interest, as far as this work was concerned, it was not different from any other shallow hole. As planking it over would have been attended with a good deal of difficulty, in removing and washing off more gravel, it was finally decided merely to fill it up with gravel and put about 10 feet of gravel on top of the dam at this point, which would bring the filling level with the general level of the bottom of the mill-pond next the dam, or would leave 15 feet of water above it. So far, therefore, from now fearing a break, a break if made artificially, would not now be of the slightest consequence. The frame-work or timbers of the dam would have to be pulled down stream and out "by the roots" before

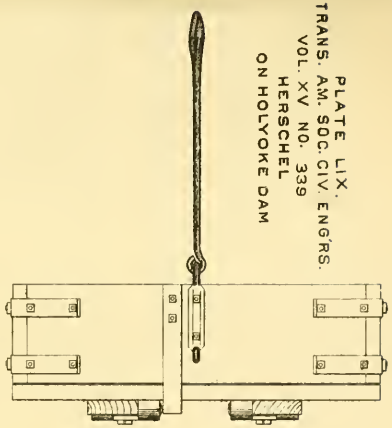
the dam could move, even if all the plank covering below the tops of the sheet-piling put in were removed, or should in course of time, by a continuance of decay, resolve itself into vegetable mould.

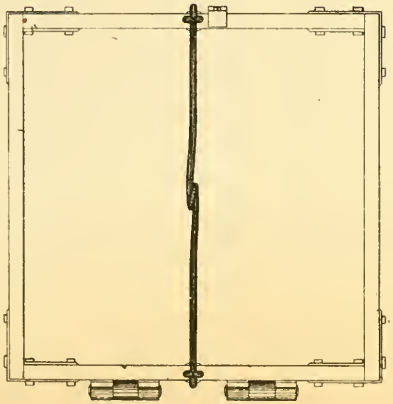
Preservation of the Timbers of the Dam.

This leads me to speak in this place of a second advantage gained by the work of 1885. It was noted above, what confidence was had in 1849 that the fact of the dam being constantly under water would keep it from rotting. Unfortunately, wooden dams don't seem to act in that way. The 6-inch hemlock plank-covering of the Holyoke dam was rotten in places—the rot working upwards from the under side—until there was not so much as $\frac{1}{8}$ of an inch of sound veneer, I can call it nothing else, left on top. This was true in case of the covering where it consisted of a single thickness of plank. From the crest, and for 20 feet down the slope, for some occult reason the covering consisted of three layers of 6-inch plank, one on top of the other. The lowest layer was fitted in between the frames of the dam, making what we called a 6-inch furring between the bents, 6 feet apart, forming the bins. This layer was mostly of the consistency of, and looked as much as anything like, sauerkraut, as it comes out of the barrel. Besides being a useless mass of rotten wood, it evidently helped rot the top timbers of the frames of the dam. But in other parts, also, the top timbers of the frames of the dam were apt to be decayed at the corners, so as to make the solid remaining part a round stick, of a section equal to a circle inscribed in the original square cross-section. Two timbers or planks butted on such a timber would lose their support, and some of the breaks were of plank thus robbed of their end-support. All timbers showing any signs of decay, within 20 feet of the crest, were, in 1885, taken out and replaced by new ones. This comprised the top layer throughout; the two top layers for about 200 feet; and in a few cases the third layer also. It is not unlikely, however, that there are still some partly decayed timbers remaining within the dam. As the dam was, these would in a short time have become wholly decayed, and it is a question what will be the effect upon such timbers of encasing them in gravel constantly kept wet, or of putting them under water. Will the decay continue and spread further, or will it be arrested? I am not aware that there has been any precise information obtained upon this question. Be this as it may, the great majority of the tim-



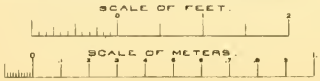


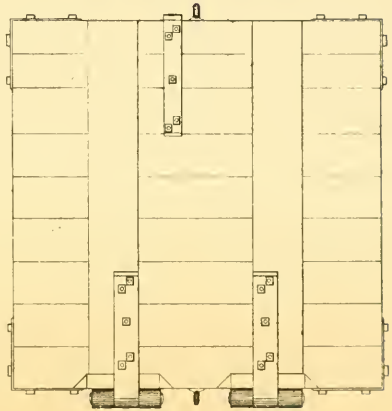




SKETCHES
TO SHOW SIDE AND END ELEVATIONS
AND TOP AND BOTTOM PLANS
OF
BUCKETS USED TO TRANSPORT GRAVEL
DURING REPAIRS ON
HOLYOKE DAM IN 1895.

HOLYOKE, MASS. JANUARY, 1896.





bers of the dam were found in a remarkably good state of preservation, and these, I am confident, have been indefinitely preserved by the work of 1885. They have been put in precisely the same condition as a timber buried in the foundation course of a bridge pier or similar structure, of which we have examples in bridges built by the Romans in a perfect state of preservation after some two thousand years of service. And this preservation of the timbers of the dam, and the strengthening of any weak ones that may be among them, by encasing them in wet, solidly puddled gravel, constitutes an important, yet mere incidental, advantage secured during the process of preventing further breaks in the covering of the dam.

Stopping of Leakage.

A third such benefit secured, likewise incidental to the main object of the work, is the stopping of leakage through the dam. At date of writing (January, 1886) the water has not been off the crest of the dam since the repairs were completed; but it was off for half a day, and, skipping the night, for the following day, when the graveling was within about 100 feet of the further abutment. Comparing the leakage that day (which included water used for puddling, and leakage, whatever it was, if any, of the incomplete portion) with the leakage of the whole dam before the break of 1884, I estimated the former as equal to about one-tenth of the latter, a not despicable gain in permanent water power.

Replanking.

The replanking of the dam offers no peculiarities not sufficiently exhibited on the drawings. See Plate LVIII. The diagram, Plate LVI, shows the rate of progress of this and other parts of the work. It will be observed that, whereas the first half of the dam required a few days over three months time, the second half was finished in just one month. The increase in skill of each particular man on a work of this sort, and as the work progresses, is very marked; and triple the speed at the end, from that achieved at the beginning, I should consider generally attainable.

Electric Lights.

Arc lights proved of the greatest advantage for carrying on the work here described, and should be set up for all important hydraulic works. Such are always liable to have a leak break out in some part, which left

to itself, over-night, may mean disaster. Here, more than elsewhere, a stitch in time saves nine. The arc light enables such stitches to be taken and kept up until the leak is under control. The lights are also of advantage in pushing the work, especially in the autumn months. Only one whole night's work was done on the Holyoke dam in 1885, but work till 8 P.M. was the rule towards the end. A luncheon brought to the men on the work at six would be done for in fifteen minutes, and in the remaining hour and three-quarters a fair quarter-day's work was often accomplished. The work done after hours was always on that one of the several operations, constituting the whole work, which happened to be behind the others. Thus the whole line was made to keep step with the most forward parties. Moving of derricks and hoisting engines was done at noon-time, or likewise after six o'clock. And generally no pains were spared to make time. Men soon learned that it was more comfortable to buy oilskin suits than it was to get wet, and as those in charge saw no reason why people on shore, or on a river, should not work rainy days as well as sailors, the many days in July and August of 1885, on which it rained, were made to do a fair, if not their full, share of pushing on the work to a successful completion.

Closing of the Last Section.

From the beginning it was anticipated that as the work in the dam would progress, the leakage of the dam, or a portion of the lineal leakage, if I may coin the expression, would be dammed back, and caused to be concentrated finally in the last section to be closed. And several ingenious plans were under consideration for overcoming the expected difficulties of this last section, one or the other or several to be employed, according to the situation as it would present itself. It was a most agreeable surprise, therefore, when no difficulties at all were encountered. The last section and the last bent of the dam filled up with gravel as quietly as any grain-bin would with corn, and the sheet piling at no time had any material head of water against it. I do not undertake to give the true and correct explanation for this; the only one appearing plausible to me is, in the first place, that the last section of the dam leaked materially less than the others. Certain it is that the river on that side had filled in much more than on the other shore, or in the middle parts. On the other hand, it is known that the middle 200 feet of the dam had for the past five years been the worst part as

to leakage. If now it be supposed, secondarily, that this leakage was practically wholly stopped by the work as it progressed, it will explain the good behavior of the last section. What little water would find its way through the gravel slope or puddled embankment, inside the dam as it was built across, could also weep through the stone filling of 1849, although the sheet-piling foots into the old filling from 2 to 5 feet, and this has itself become thoroughly grouted with river silt and sand; and this much water could also leak through the sheet-piling, which makes no pretense to the tightness of good coopering. The above considerations lead me to expect, also, that the work done in 1885 will approximate more and more, as time goes on, to being absolutely water-tight.

Cost of the Work.

This cannot be precisely stated, for the reason that the expensive repairs of 1884, and of the break of 1885, were charged to the same account. My best estimate puts it at about $65 000, inclusive of cost of dredge, railroad tracks, boxes, scows, one hoisting engine, derricks, tools and plant generally.

The credit given in 1849 to A. C. McNary, as "foreman of mechanics," should be repeated for the work of 1881 to 1885 in behalf of Mr. Paul Hurlbut, of Holyoke. Mr. Paul Hill, of Billerica, also did efficient service at a critical time. And a general meed of praise should be accorded to the 100 or more French Canadians, "born with an ax in their hand," who did most of the carpenter and other intelligent work required.

The Lesson of 1849 to 1886 in the Construction of Wooden Dams.

Speaking of the lesson above cited as it presents itself to me, I should say: *First and foremost.* That a wooden dam should never be left hollow, nor should it be filled with stone. Let a row of sheet-piling be put in, in some proper position, then puddle in gravel. Gravel is water-tight, or soon becomes so; stone filling is not. Gravel will protect every timber it encases from rot forever; stone filling will permit decay, and so will the moist, foul air to be found in the interior of all hollow dams. Worst of all is a dam entirely hollow.

Secondly.—In crib work, two timbers should never be butted on top of another of the course next underneath. This would give each timber at the most a 6-inch bearing, and should the lower timber become decayed at the edges, or the butting timbers at the ends (both being places

where decay is worst), the strength of the bearing is speedily reduced to zero. It looks well on a drawing, or in new work, thus to butt timbers and the covering plank. But a great deal may be learned in pulling an old dam to pieces, and were I to design a new dam I should do neither.

Thirdly.—Don't make a masonry shelf on each abutment to take the place of the last bent or frame of the dam. When the dam settles, or compresses under its load, as it must, the shelf does not follow, and the result is a distortion of the framing of several bents next the abutments.

Fourthly.—The back of the dam needs to be guarded against such abuse as the dropping of 4-ton stones upon it, especially in the case of dams upon large rivers.

Fifthly.—The shape of a dam should be chosen with a view to preventing the excavation of large masses of the river bed, and the formation of a pool below the dam, in all cases. It is absolutely necessary to do this in the case of a gravel bottom; it should never be neglected in case of a soft rock bottom; it should be done in many cases of a granite or other hard-ledge bottom. A pool of water that cannot be laid dry is a source of danger in all hydraulic works, for the reason that one can never be certain as to what may or may not be taking place below the water surface; unless, indeed, periodical inspections be made in diver's armor, and even that would result in far less frequent examinations.

This brings me to a consideration of the shape which should be given dams, so as to protect the bottom of the river next down-stream, and as developed in the studies made in view of the possible construction of a stone dam at Holyoke. I will only say here, that the same general principles could, and should, as it seems to me, find application in the designing of wooden dams also.

Design for a Stone Dam at Holyoke.—See Plate LX.

In starting out upon this design, I made it a condition that the water, in falling over, should not again attack the river bottom, or should not cause the excavation at Holyoke of a pool No. 3; and that the dam should be amply able to hold a pressure of 15 feet over the crest. My first idea was to build a dam in steps. This shape has shown itself of good service for the reverse problem—that of breaking up the force of ocean waves. "Compel the water to walk upstairs," was said by a distinguished European engineer, "and you soon tire it out." However that may be for the upstairs transit, in going downstairs

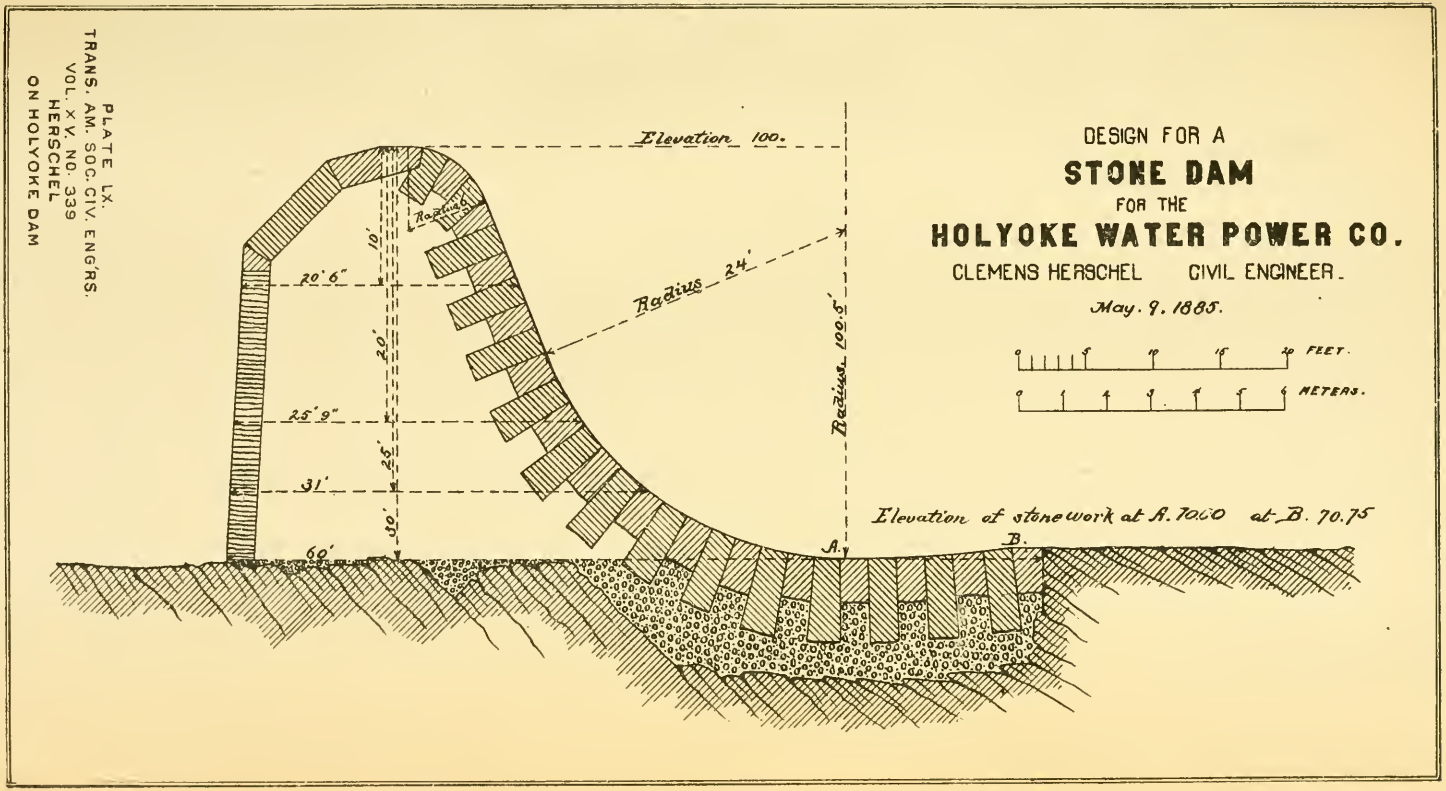


PLATE LX.
TRANS. AM. SOC. CIV. ENG'RS.
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HERSCHEL
ON HOLYOKE DAM
DESIGN FOR A
STONE DAM
FOR THE
HOLYOKE WATER POWER CO.
CLEMENS HERSCHEL CIVIL ENGINEER.
May. 9. 1885.
FEET.
METERS.
Elevation 100.
Radius 8'
Radius 24'
Radius 100.5'
20'6"
25'9"
31'
60'
10'
20'
25'
30'
A.
B.
Elevation of stonework at A. 70.60 at B. 70.75

water has a way of acquiring velocity in falling over the first riser from the top, and in virtue thereof, of skipping the second and most of the succeeding steps. Its progress becomes like a perpendicular fall in the case of one proportion of rise to tread, and becomes like unto boys sliding down the hand-rail of stairs, in the case of smaller risers and treads. In either case the bed of the stream at the foot of the stairs is very violently attacked.

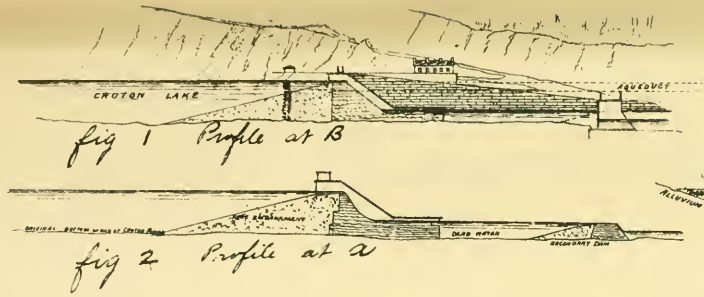
The ogee form seemed to offer a solution of the problem, and several of these were next experimented with. Models were built on a scale of $\frac{1}{12}$ full size. Set up in an old canal-lock, a miniature 12-foot freshet could be poured over them to the great satisfaction and instruction of all concerned. The thing to be aimed at, was evidently to pass the water over the dam without allowing it to change its color. The moment it ceased to slide over, and commenced to fall, at any part of the transit, it would become white, or whitish. The exactly correct form to accomplish this, and no more, would be different for different depths upon the dam, greater depths requiring more base of dam, lesser depths jutting out less. But no harm is done in giving more base for the lesser depths, and some assumed depth may always be used in the computation of the proper down-stream curve of the crest and body of a dam, if the way by computation be preferred. The reverse incline at the foot of the dam was put there to destroy acquired velocity of the water, and to protect the bed of the river next down-stream from the dam. Too much lift, however, produces another fall below the lift; too little, on the other hand, destroys less acquired velocity than is feasible, and also erodes the bed of the river. I selected the slope shown, solely by experiment, and its final result is a sliding over of the stream of water until it is projected down-stream, apparently in a horizontal direction, and exactly parallel to the bed of the stream. The rise of the lift above a tangent to the lowest part of the apron, as finally adopted, was in the model $\frac{3}{4}$ inch. A lift of $1\frac{1}{4}$ inches had a materially different effect upon the sheet of water, 12 inches thick, passing over. Experiments made with the bed of the stream, represented by a box of pebbles, showed no undertow next the end of the lift. At this point the bank of pebbles remained intact, with the representation of a 12-foot freshet going over the dam.

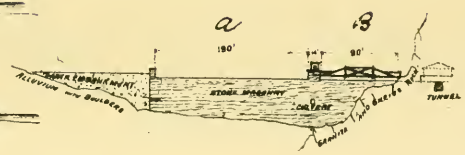
My attention has been called, since commencing this paper, to the cross-section of the dam at the outlet of Croton Lake, which is likewise

of an ogee form, only that the period of experimenting seems there to have been passed through with a model of full size, built on the site of the work itself; in other words, with the work itself. I was in entire ignorance of a dam with a curved front face in this country, at time of studying this question. As the Croton dam may not be widely known, a cross-section is here reproduced, Plate LXI. It will be observed that the reverse slope was added at a later day, and being constructed of wood, it had to be protected from decay by the secondary dam below. A waste weir permits the drawing off of the pool between the two. As this is a case of a gravel bottom, and this bottom is, moreover, several feet below the level of a horizontal continuation of the down-stream end of the lift, or reverse slope, the pool also serves as a protection to the bottom of the river below the dam. Another way to accomplish the same object would be, however, to make the down-stream end of the lift in line with the bottom of the river, and to secure or protect this bottom in an effective manner. The cross-section shown on Plate LX was especially designed for the situation at Holyoke, which, it will be remembered, has a river bottom of ledge, of a consistency varying from soft to hard rock, all the way across. There is a dam of an ogee shape in Spain, built by Sir James F. Bateman, the well-known English engineer. It may be found described in Moncrieff's "Irrigation in Southern Europe." This is the work (together with some more or less theoretical statements in various hand-books of hydraulic engineers), which first called my attention to this form of dam. As perfected by further studies, it clearly results in a fairly successful method of seeking "to convert, adapt, and apply the great sources of power in nature to the use and convenience of man." I believe that the engineer can never keep too closely to the pursuit of the high aim in these words set before him.

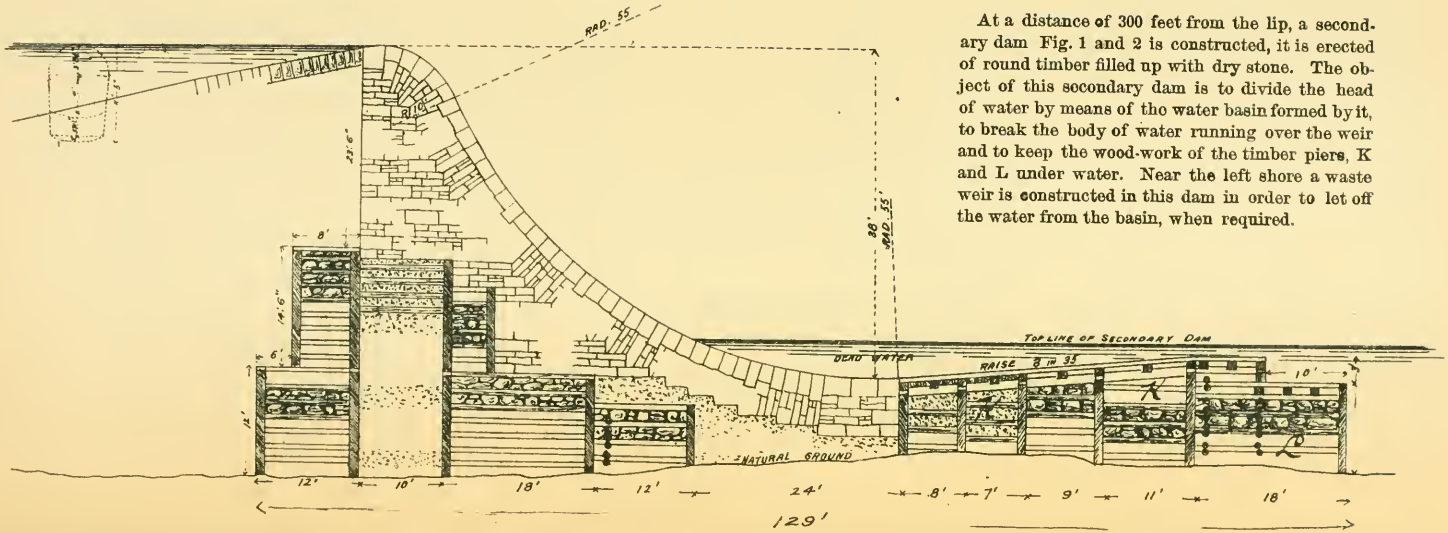
Description of the Photographic Views.

Plate LXII, July 10th, 1885.—In the foreground is the thirty-foot piece, between end-piece No. 1 and the Holyoke abutment, filled with gravel and being replanked. Section 1, just beyond end-piece No. 1, has been laid dry, and the crest-plates have been stripped off. Next beyond is the diver's boat, and abreast of it, the dredge, the capstan boat and a scow. In the distance some men are struggling to get the crib of





DAM AT OUTLET OF CROTON LAKE.



At a distance of 300 feet from the lip, a secondary dam Fig. 1 and 2 is constructed, it is erected of round timber filled up with dry stone. The object of this secondary dam is to divide the head of water by means of the water basin formed by it, to break the body of water running over the weir and to keep the wood-work of the timber piers, K and L under water. Near the left shore a waste weir is constructed in this dam in order to let off the water from the basin, when required.

1885 to penetrate the *debris* under its up-stream edge, by driving sheet-piling for the third or fourth time.

Plate LXIII, July 30th, 1885.—In the foreground is the 30-foot piece next the Holyoke abutment, replanked and iron crest and flash-board pins put back, timbers on crest and on the coffer, ready for unloading the coffer; same state of affairs in Section 1, with the long timbers just being put on. Gravel is being dumped into Section 2, and the diver's boat lies just beyond end-piece No. 3. Still struggling with the crib of 1885, this time with the pump-boat and the water-jet. The dredge at work with the clam-shell bucket.

Plate LXIV, August 5th, 1885.—In the foreground is the 30-foot piece next the Holyoke abutment, with 2 foot flash-boards on the crest, and water let over this piece, and into Section 1. In the foreground, men removing the timbers which had served to hold the stone ballast of the coffer abreast the 30-foot piece; and next beyond, the stone ballast of end-piece No. 1, and of the coffers of Section 1, may be seen supported by similar timbers. Next beyond is Section 2 being replanked, and beyond this is Section 3, still full of water, but nearly ready for closing the gates in the coffers. The water was got out of this section next day, August 6th. The boom of logs in the river is one that had broken away, up-river. Coming down upon the works they stopped the gravel filling for two days.

Plate LXV, September 1, 1885.—Showing Section 5, just after being stripped of the old plank and top course of timber, with new timber going on. In the foreground may be seen the sheet-piling of one "bin," the ends of the plank not yet sawed off even.

Plate LXVI, September 8th, 1885.—View from the shore. In the foreground the gravel train and steam derrick; loaded scow going out, and scow-load of empty buckets coming back. Two 50-foot coffers afloat, point down, abreast the outer scow; the crib of 1885, subdued and brought down into place, just beyond this scow, with the "plug" built in place, of 3-inch plank, on the side facing the shore. The dredge and the two divers' boats, hard at it, in the distance.

Plate LXVII, September 18th, 1885.—A view from South Hadley Falls abutment. End-piece No. 9 just run in, visible next the abutment. Then the diver's boat with the diver sitting on his iron ladder. Behind this boat a 50-foot coffer afloat, flat side up. Up-stream from this another 50-foot coffer afloat, point down. Gravel going into Section 7, and

the coffers of Section 6 being unloaded. The city of Holyoke in the background.

Plate LXVIII, September 18th, 1885.—View of Section 7. The old man on the extreme right, E. H. Humes, of Greenfield, helped build the dam of 1849, the apron of 1868–70, and worked on the dam the whole season of 1885. The row of sheet-piling is shown; gravel is going in, and the carpenters in replanking are crowding the gravel dumpers.

Plate LXIX, September 18th, 1885.—Practically the same as Plate LXVIII, but about an hour later. The three lines of hose have been shifted and now show under the gravel bucket.

PLATE LXII.
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HERSCHEL
ON HOLYOKE DAM.

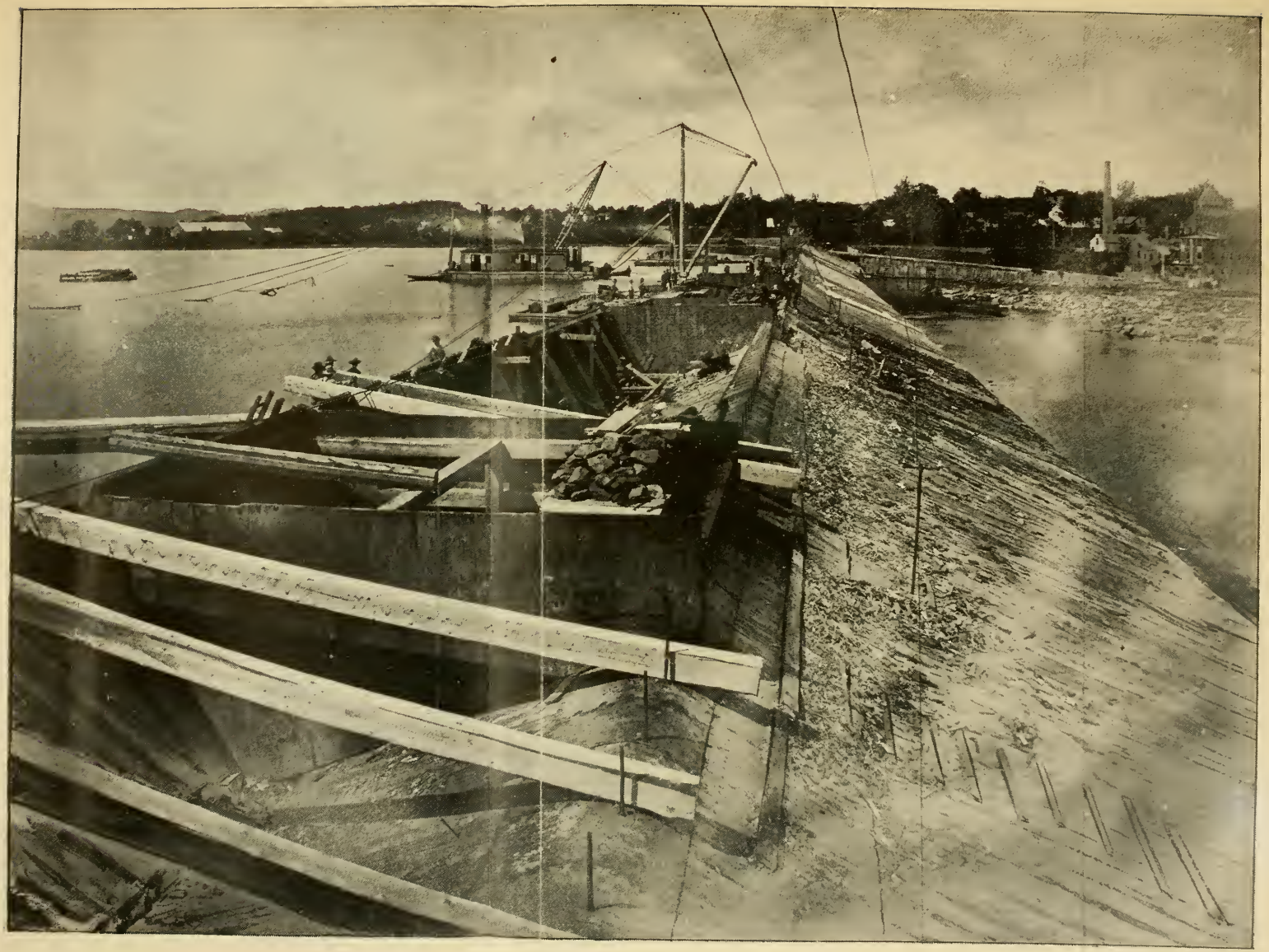

PLATE LXIII.
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HERSCHEL
ON HOLYOKE DAM.

PLATE LXIV.
TRANS. AM. SOC. CIV. ENG'RS.
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HERSCHEL
ON HOLYOKE DAM.

PLATE LXV.
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HERSCHEL
ON HOLYCKE DAM.

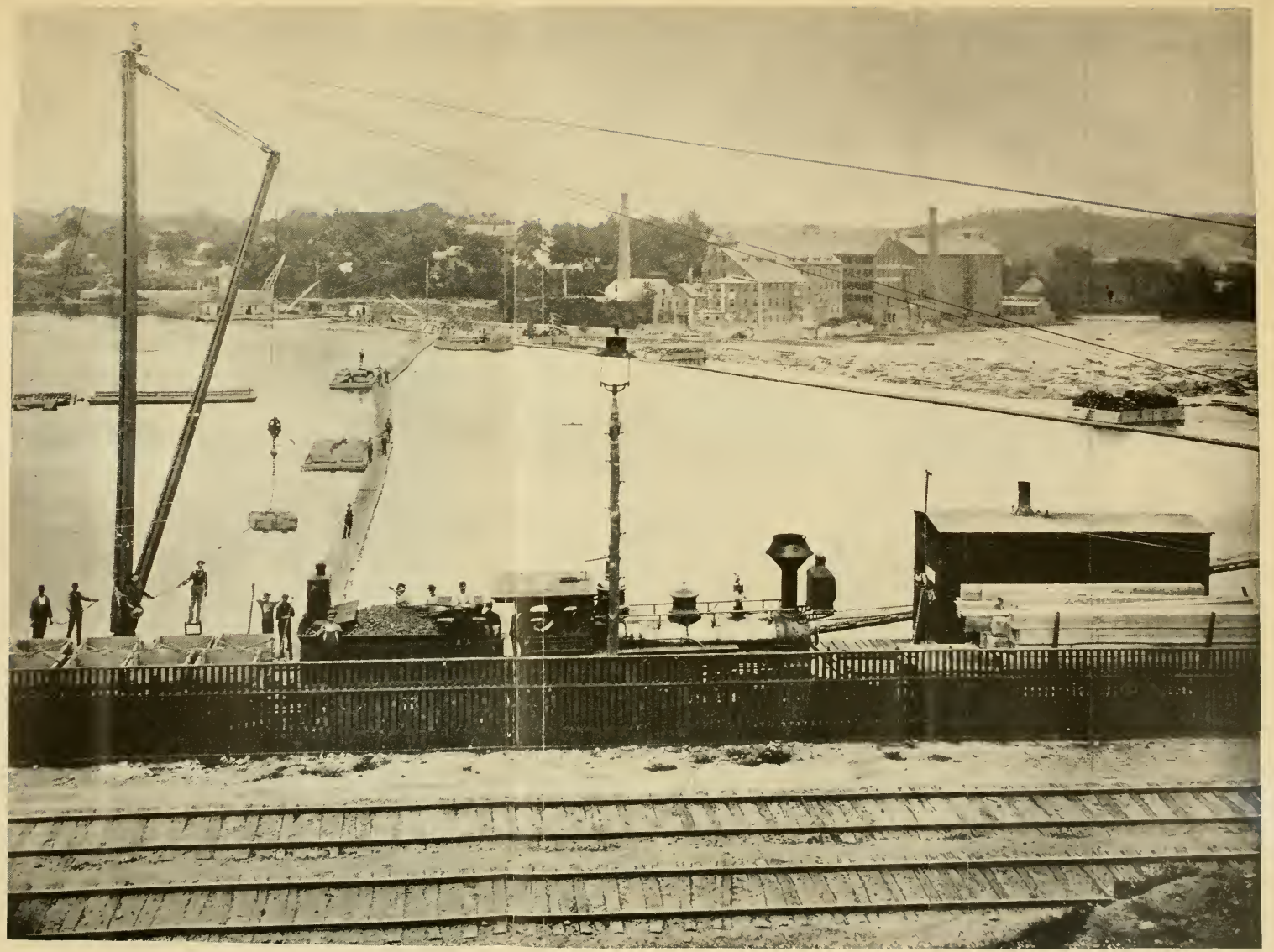

PLATE LXVI.
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HERSCHEL
ON HOLYOKE DAM.

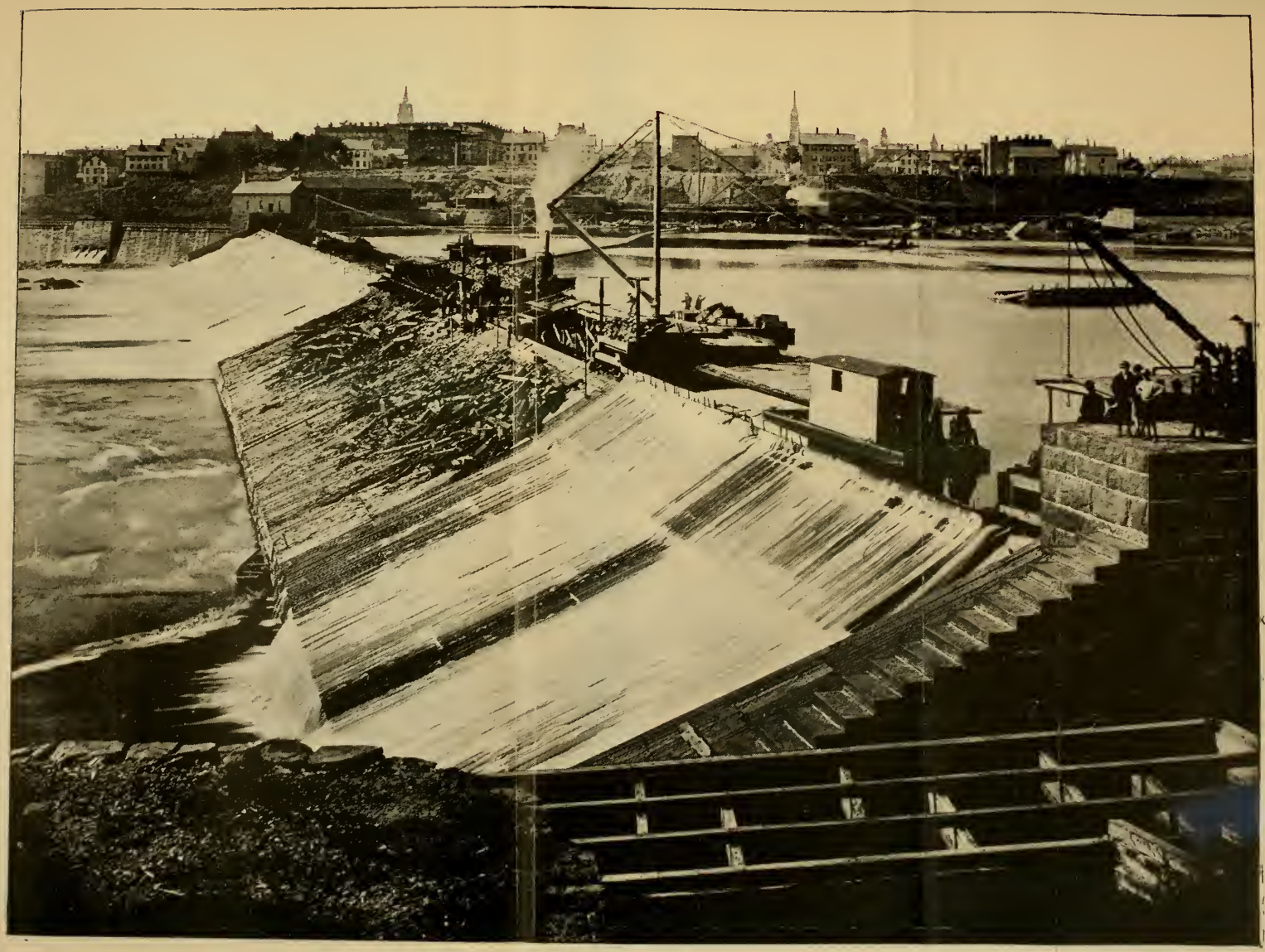

PLATE LXVII.
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HERSCHEL
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PLATE LXVIII.
TRANS. AM. SOC. CIV. ENG'RS.
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HERSCHEL
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PLATE LXIX.
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HERSCHEL.
ON HOLYOKE DAM.

AMERICAN SOCIETY OF CIVIL ENGINEERS.

INSTITUTED 1852.

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340.

(Vol. XV.—September, 1886.)

EVAPORATION.

By DESMOND FITZGERALD, M. Am. Soc. C. E.

READ MARCH 17TH, 1886.

INTRODUCTORY.

Nearly two years ago the writer received an invitation from the American Society of Civil Engineers to submit a paper upon Evaporation at its last annual convention. Having already experimented upon the subject for several years and accumulated a certain mass of data, the invitation was accepted, under the supposition that it would not prove a very difficult task. On reviewing the whole subject, however, it became evident that a more extensive series of experiments would have to be entered upon than any previously undertaken, to throw light upon certain points which will appear in the course of this paper. These were at once begun and have been prosecuted diligently ever since. The theoretical side of the question was surrounded with so many difficulties, that the writer found it necessary to experiment in many branches of meteorological work in order to arrive at correct conclusions. The larger part of these experiments being more in the nature of preparatory work, are not alluded to at all in this paper. Before proceeding

further, the writer desires to acknowledge his indebtedness to the Boston Water Board for the liberality with which they have allowed these experiments to be prosecuted, and to Mr. Fred. Brooks, M. Am. Soc. C. E., for material assistance received in the preparation of this paper.

As will be seen, the experiments and discussions are confined prinpally to the natural evaporation from water surfaces.

The importance of this subject may not appear at first glance, for it is only after a considerable course of study that the breadth of the field becomes visible. It is desirable for the hydraulic engineer to know, with more precision than is generally practicable, the approximate loss from water surfaces in the course of the year, for there are many estimates made in which this amount is really guessed at.*

For the meteorologist, who surveys a wider horizon, the path to a more extended solution of many of the difficult problems connected with the formation, distribution and condensation of vapor in the air may be somewhat smoothed, if, in addition to pointing out the amount of natural evaporation under given conditions, the laws which govern this amount can be demonstrated with considerable exactness.

Part I.

Investigation of the Law of Evaporation.

Considering the importance of the subject, comparatively little has been written on the theory of evaporation. There is undoubtedly a great deal of valuable matter scattered through various scientific periodicals, principally relating to the several meteorological phenomena connected with evaporation, but the terms employed to signify the same things are so diverse, and the methods of treatment so different, that much perplexity must necessarily result from their study.

It will be impossible in the limited space which has been set aside in this paper for the theoretical portion of the discussion, to attempt anything like a complete or scientific review of the theories or facts connected with evaporation, even were the writer fitted for the task. But it seems desirable to present, as briefly as practicable, some of the prin-

* The evaporation from the Ganges Canal in Northern India was estimated on the basis of the "Roorkee" experiments to amount to 47 cubic feet per second, but from what the writer has been able to learn of these experiments, the engineers must have been very much disappointed in the results.

cipal facts which it is absolutely necessary to understand in order to get an idea of the subject.

In accordance with the dynamical theory of the constitution of bodies,* evaporation is constantly taking place at a rate due to the temperature at the surface, and condensation is likewise going on from the existing vapor in the air passing into the water, the difference between the two processes being what we call the rate of evaporation.

If a little water be introduced into the vacuum over a barometric column of mercury, the vapor which immediately forms will expand with a force due to its temperature and cause the mercury to fall to a point which forms the measure of the expansive power of the vapor. If now the temperature of the vapor be raised by applying heat, the mercury will fall still more; while on the other hand, if the temperature be lowered, the force of vapor becomes less and the mercury rises. In this way the maximum forces of vapor may be expressed in inches of mercury. We owe to the admirable experiments of V. Regnault an accurate table of maximum forces of vapor for different temperatures.

These values form the basis for almost all the tables in which humidity plays a part. They were made at the expense of the French Government, and will be found fully described in the Memoirs of the French Academy.

All air found in a natural condition contains more or less of this gas which we call vapor. Even the dry air blowing over a heated desert contains a small amount, and it is this amount which largely influences the rapidity of evaporation.

The rate of evaporation depends upon the difference between the maximum force of vapor due to the temperature of the water and the force of vapor existing in the air. If the force of vapor actually present in the air be small and the temperature of the water be high, evaporation will proceed with great rapidity, and, on the other hand, the rate will be diminished as the two forces approach each other in value.

It is necessary not to fall into the error of supposing that the rate of evaporation from a pool of water bears any direct relation to the relative humidity of the air. This might be the case if the temperature of the water surface followed the air, even approximately, in its changes of temperature. Many writers of the highest reputation have evidently assumed this to be the case.

* Wm. Garnett, Enc. Brit., Vol. VIII, p. 732.

Let us examine somewhat closely into this matter of relative humidity, and see what it really is, and what its relations to evaporation are. Space has a capacity for vapor depending upon its temperature, so that if there is a given definite amount or weight of vapor in the air at a certain temperature, the relation which this vapor bears to the whole vapor-carrying capacity of the air is very different from the relation which the same amount of vapor bears to the carrying capacity of the air at another temperature. This relation is commonly called the relative humidity. This relative humidity is a capital measure of the effect on our senses of the humidity of the air, for at a given temperature and with a certain amount of vapor the air may seem very damp, while at a higher temperature, and with exactly the same weight or force of vapor, the same air may seem very dry. It has been shown by many celebrated physicists that air of a given temperature becomes saturated when there is a certain amount of vapor present, and it can be made to take up no more vapor unless its temperature be raised. Any surplus vapor must be condensed. This vapor present in the atmosphere has, as a gas, a certain pressure, or tension, or force, whichever term we care to use to express the same thing, dependent entirely upon the temperature.

The following will be found to be the changes which ordinarily take place in humidity during a day. In the latter part of the night, say at 4 A.M., the air is chilled to its minimum temperature, and supposing always that there is a certain definite force of vapor in the air—and, as a matter of fact, it does not differ so very much in amount from hour to hour, at any rate not sufficiently to affect our discussion—we shall then have a very large relative humidity, perhaps little short of saturation. The air, to the senses, will then appear to be not only cold, but damp. As the sun makes its appearance and warms the air, the relative humidity decreases, until at 2 P.M., a common hour of maximum temperature, the relative humidity is at its lowest point. The force of vapor, however, may be, and we here assume it to be, the same in both cases. By glancing over the table of hourly observations, the exact amounts commonly found at different hours may be seen, and the profiles, Plate LXXXI, give in a graphical form, for three successive days in July, all the meteorological changes from hour to hour.

Now, if the temperature of the water be the same at 4 A.M. and at 2 P.M., the hours under consideration, evaporation will be going on at exactly the same rate. An examination of the diagrams plotted by a

recording instrument, one of which is given, Plate LXXVI, shows very little difference in the rate of evaporation at different hours of the day, as we might expect from the foregoing.

The following example, taken from the hourly readings of June 23d and 24th, 1885, will illustrate the above point. From 8 to 9 P.M. the mean relative humidity was 68 per cent. and the mean force of vapor in the air 0.311 of an inch of mercury. From noon to 1 P.M. the mean relative humidity was just half the former, or 34 per cent., and the mean force of vapor 0.305. The rate of evaporation was about the same during both hours.

If the temperature of the air be at any time lowered to a point where the vapor present would begin to condense; or, in other words, where the air would be fully saturated by the amount of vapor present, that point is called the dew point. If we know the temperature of the air and of the dew point, all of the other hygrometrical conditions may be easily computed. The dew point is a most important factor in evaporation, for as the dew point varies, the force of vapor varies, and, other things being equal, it is the difference between the temperature of the water and of the dew point that determines evaporation. If the water be cooler than the dew point, no evaporation can take place; on the contrary, the cooler water would condense some of the vapor in the air. But if the dew point be lower than the temperature of the surface of the water, evaporation must be taking place.*

The practical determination of the force of vapor in the air, or of the relative humidity, or of the dew point, is generally made by observing the difference between the wet and dry bulb thermometers; but from many observations made by the writer during both summer and winter, he is led to doubt the accuracy of common readings of these instruments. A more trustworthy method of securing good results is to take a direct observation of the dew point by means of some condensing apparatus, of which there are several good forms; but the use of such instruments is certainly far from convenient.

We have now reached a point where we may tabulate intelligently the principal points to be considered in the study of the vapor of the atmosphere, and we can hardly do better than to follow the order used by Buchan.†

* The difference between the temperatures of the air and of the dew point is called by some writers the complement of the dew point.

† Article "Atmosphere," Enc. Brit.

They are:

1. The temperature of the air.
2. The dew point.
3. The force of vapor.
4. The quantity of vapor in, say, a cubic foot of air.
5. The additional vapor required to saturate a cubic foot of air.
6. The relative humidity.
7. The weight of a cubic foot of air at the pressure at the time of observation.

Numbers 3 and 4 may be taken as approximately the same.

To John Dalton, a most accomplished philospher, is due the credit of first pointing out in an approximate form the measures of the maximum forces of vapor. His experiments have been termed "slovenly," and they are certainly lacking in the accuracy of experimenters who have followed in his footsteps. Dalton's work was to discover many grand truths which others have spent their time in defining with accuracy.

He was the first to ascertain the true principles of evaporation. From some observations made by the writer on the Dalton law, he was led to believe that the rate of evaporation in calm air was not in exact proportion to $(V - v)$ as generally accepted, and the following experiments were made under cover in a shop to determine the relation.

Influence of Heat on Evaporation.

Plates Nos. LXX and LXXI give plan, elevation and sections of special apparatus designed to determine the effect of heat on the rate of evaporation Three evaporating pans, *A A A*, 14.85 inches in diameter (in which 1 ounce of water equals 0.01 inch in depth), were fixed on the brass spindles which extended downwards through the tanks *B B B*. At the lower extremities of the spindles were attached plates which fitted on to a Fairbanks' weighing scale. The tanks were kept full of hot water at different temperatures, supplied from a steam boiler through the pipes, as indicated. The bottoms of the evaporometers and the tops of the tanks were made of plates, ground to fit accurately, so as to insure the equal distribution of heat to the pans. In their normal positions these pans rested on the tanks. Underneath this apparatus a small track carried the weighing scale, which was mounted on trucks and graduated to one-eighth of an ounce. This scale could be rolled successively under each of the pans, and by pressing on a lever

Evaporating Pans.

PLATE LXX.
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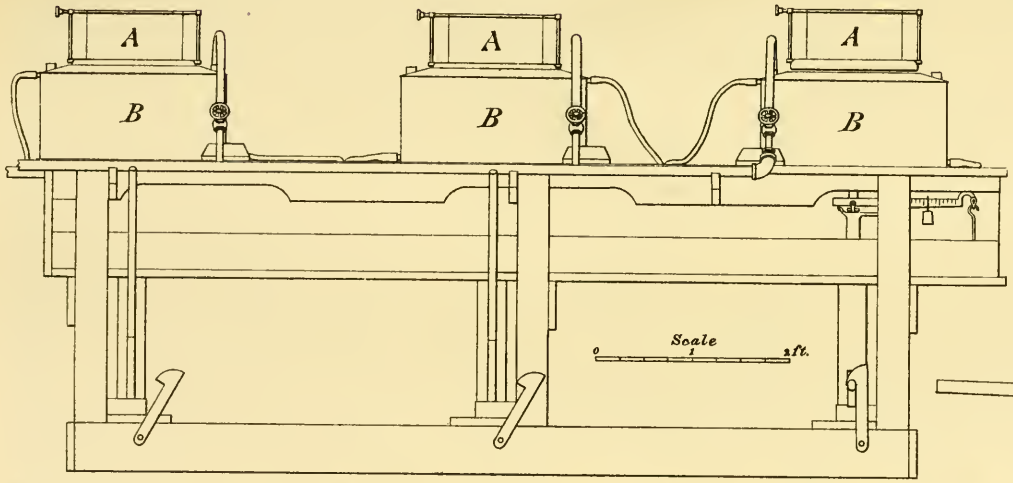
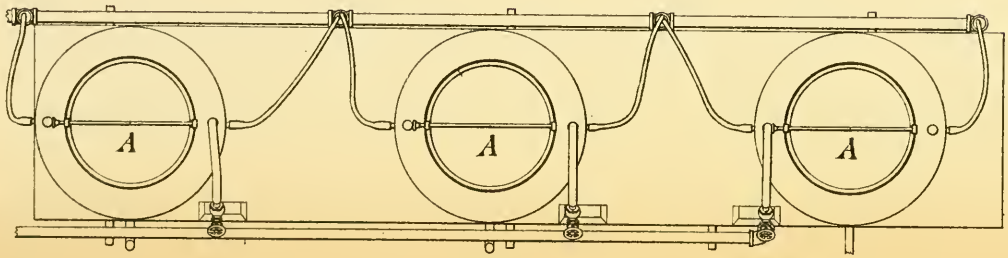
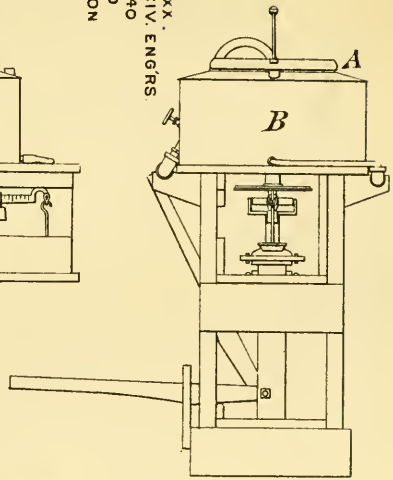
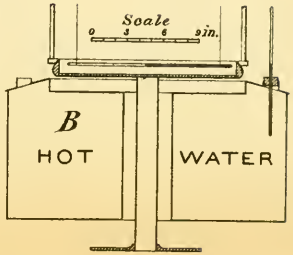
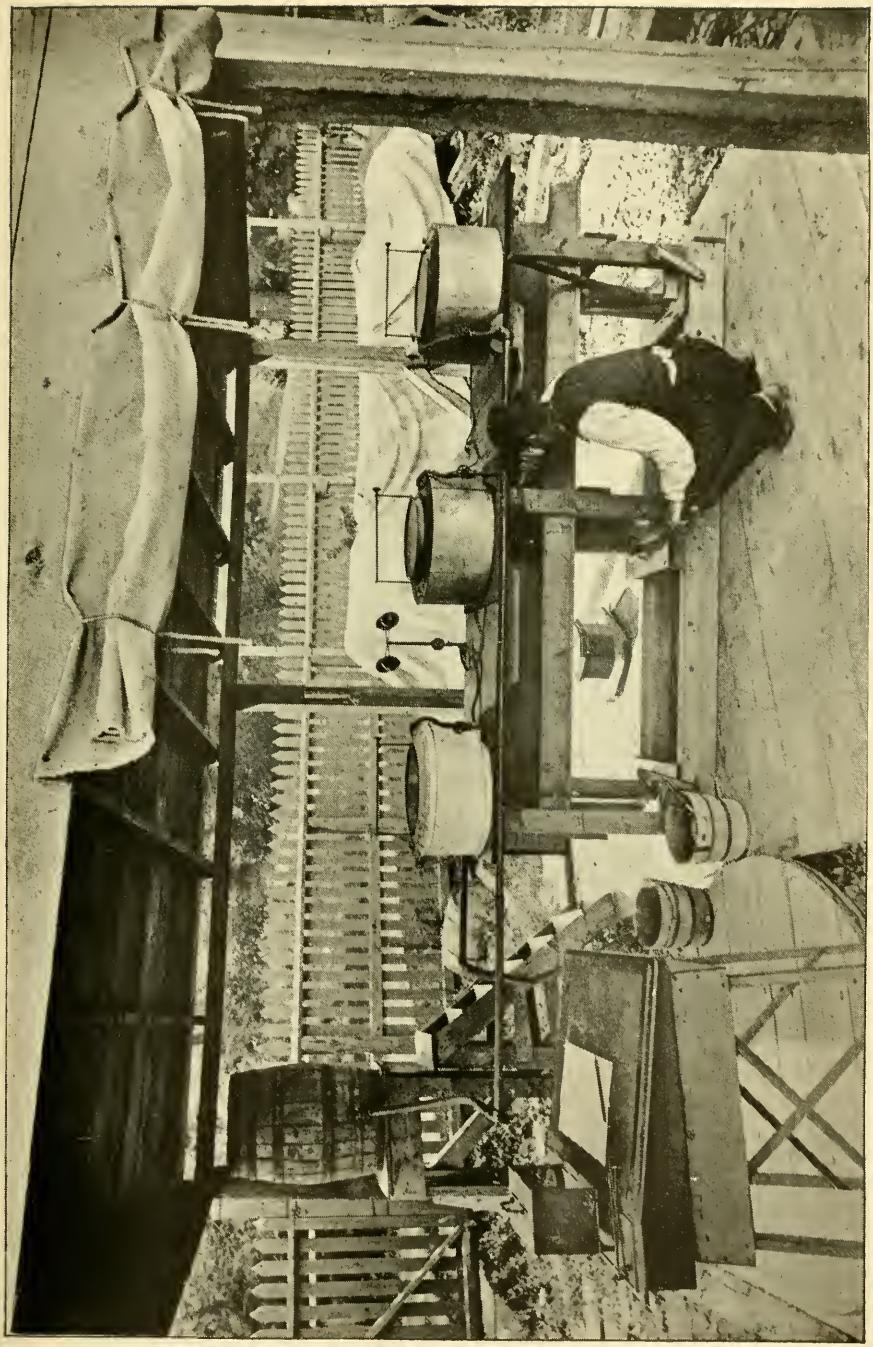
FITZGERALD
ON EVAPORATION











both pan and scale were raised slightly and the weight of the pan taken. The objects of the apparatus were to keep each evaporometer at some definite temperature for several hours, and to weigh the water at given intervals without spilling the contents, and so quickly as not to change the temperature materially.

The thermometers were suspended by very fine wires, so that the whole length of a glass was just beneath the surface. A screw permitted the lowering of the thermometers as the water evaporated. The temperatures were recorded every 10 minutes to the nearest 0.1 degree C., and the weights taken every half hour.

Psychrometers were read at the same time. By keeping the three pans at widely different temperatures at each experiment, the effect of temperature could be noted independent of other conditions.

Table No. 4 gives the results of 154 experiments.

As this work progressed the observations were plotted on a large scale, as a working drawing for aiding the study of the effects of varying temperatures. The values of $(V - v)$ were taken as the abscissas and the evaporation in decimals of an inch per hour as the ordinates.

V in this paper means the maximum force of vapor in inches of mercury corresponding to the temperature of the water; v the force of vapor present in the air; and E the evaporation in inches of depth per hour.

Simultaneous observations were connected by lines of the same color for facilitating the comparisons. Plate No. LXXII contains all these experiments on a small scale, with the mean curve as finally adopted. All of the circles were not given equal weight in determining the curve, as it was found that the position of one of the pans near a somewhat open partition in the room where the experiments were made seemed to have a slight influence on the rate of evaporation. This irregularity was investigated by special experiments.

In order to ascertain whether any lateral or other currents of air were set in motion by increased temperature in one pan which were not felt in the others, cloth hoods 6 feet in height were used during a portion of the observations. These screens surrounded the tanks, and were used both open and closed at the top, but no effect on the curve was noticed. Other experiments were tried, such as keeping different depths of water in the pans, changing thermometers, and the relative position of the pans, etc. The mathematical expression of the curve is

$$E = .014\,(V - v) + .0012\,(V - v)^2.$$

The Effect of Wind.

When a water surface is exposed to the movements of the air we find that the velocity of the wind ranks in importance next to the difference in the forces of vapor as influencing the rate of evaporation.

The exact effect has never been determined so far as the writer can ascertain. Dalton found that a strong wind doubled the result produced in a still atmosphere, and his tables contain the corrections to be made for a moderate breeze and a brisk wind.*

In order to measure the influence of the wind with more precision, the evaporating pans were moved out into the open air. An anemometer was placed with the cups at the same level with the water in the evaporators, and the temperatures, weights and forces of vapor were recorded as in former experiments. Table No. 5 gives the results. The range of velocities was not so great as the writer would have liked, but there are many difficulties in the way of experimenting in high velocities, such as water blowing out of the pans, incorrect weighing, etc.

As confirmatory of the general accuracy of the curve, it was found that the increased rate of evaporation for higher values of $(V-v)$ was seen in the experiments in the open air as well as in those in the shop, so that it cannot be supposed that the greater evaporation from warmer water was due to air currents that heat might have started.

These wind experiments were plotted on the same scale as the former ones, with $(V-v)$ as abscissas and the evaporation as ordinates. The plotted lines connecting simultaneous observations when the wind was constant for all the pans then exhibited the way in which the evaporation varied with different values of $(V-v)$. By following the lines corresponding to particular values of $(V-v)$ and noticing where they crossed the plotted lines of the experiments with different wind velocities, the way the evaporation varied with the wind for any particular $(V-v)$ could be studied. It was found that for all values of $(V-v)$ the evaporation in any particular wind was about the same number of times the evaporation in any particular slower wind or in calm. According to these general views, suppose that when $w=0$ the evaporation varies with changes in $(V-v)$ so as to be equal to $.014\,(V-v)+.0012\,(V-v)^2$ then with $w=$ any other particular value, the evaporation would vary with changes in $(V-v)$ proportionately to $.014\,(V-v)+.0012$

* Minutes of the Lit. and Phil. Soc'y of Manchester, Vol. V, Part 2, p. 584.

$(V-v)^2$. As long as the wind is the same, the evaporation is supposed to be a fixed number of times $.014\,(V-v) + .0012\,(V-v)^2$. The cases where $w=0$ were selected for use in determining the mathematical expression, because there were more of them than of any other one value of w, and they were liable to less uncertainty. By means of the foregoing, there could be determined from each experiment with its particular value of $(V-v)$ as determined from the observations what the evaporation ought to have been if $(V-v)$ had been 1. Suppose these hypothetical evaporations to be computed for all the experiments, then it may be said that this hypothetical evaporation is $(.014 \times 1 + .0012 \times 1^2) = .0152$ times a quantity fixed according to the wind. From this it follows that this hypothetical evaporation divided by .0152 is the wind factor, which is about $(1 + 0.67\,w^{\frac{3}{5}})$, w being the velocity of the wind in miles per hour, as determined by the aid of a diagram made by plotting miles per hour of wind as abscissas and as ordinates the quantity

$$\frac{\text{Evaporation in inches per hour}}{.014\,(V-v) + .0012\,(V-v)^2}$$

This quantity was obtained by computation for each item in the table (See Table 5), and corresponds to the wind factor required for the formula or $\frac{1}{.0152}$ times the hypothetical evaporation alluded to. By drawing a mean line to represent as nearly as possible all the items plotted, and substituting the mathematical expression as a multiplier of $.014\,(V-v) + .0012\,(V-v)^2$ the formula for evaporation becomes

$$E = [.014\,(V-v) + .0012\,(V-v)^2]\,(1 + 0.67\,w^{\frac{3}{5}})$$

As the curves on the diagrams are comparatively slight, an approximate formula can be conveniently obtained by plotting, both on the temperature diagram, Plate LXXII, and on the wind diagram above alluded to, straight lines instead of curves, to fit the experiments. This approximate formula, being an equation of the first degree, becomes much simpler, and will be found sufficiently accurate for most practical purposes, and is as follows:

$$E = .0166\,(V-v)\left(1 + \frac{w}{2}\right)\text{; or}$$

$$E = \frac{(V-v)\left(1 + \frac{w}{2}\right)}{60}$$

Barometer.

It will be noticed that no allowance has been made in the above formula for the barometric pressure.

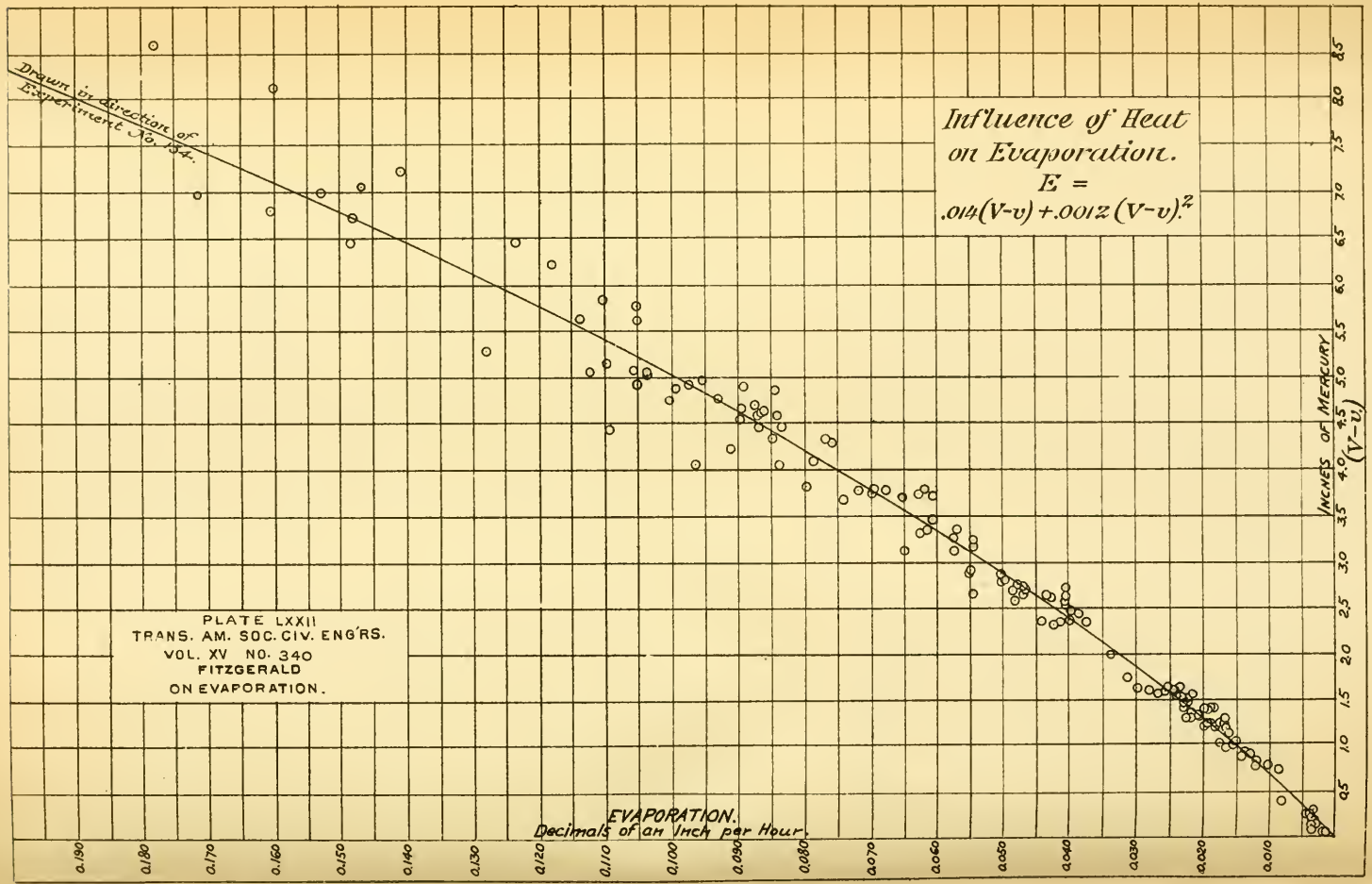
The height of the barometer during each experiment was plotted on the diagram Plate LXXII, but no connection could be traced between the deviations of the experiments from the mean curve and the atmospheric pressure. The writer, after a careful examination of the subject, concluded that ordinary changes in the mercurial column are so slight that they may be safely disregarded as far as their influence on the rate of natural evaporation is concerned.

The same result was reached by Stelling in the Russian experiments. Daniell concluded from many experiments in vacuum that it is not the pressure of the air which affects evaporation, but that the mechanical impediments of the molecules of the air, like the pebbles in the course of a stream, impede the operation, and that the influence of the atmosphere on the rate of evaporation is in inverse proportion to its pressure. The writer has made a series of experiments, under a large bell glass, in vacuo to ascertain the effects on evaporation. It was found necessary to use a condensing apparatus to get the correct force of vapor, on account of the untrustworthy results of the wet bulb thermometer.

The general result of the experiments was to confirm the opinion expressed by Daniell, though sometimes the evaporating dish, which was 3.25 inches in diameter, lost so little of its weight, even after several hours exposure in a vacuum with a large dish of sulphuric acid to absorb the vapor as fast as it formed, that the formula seemed as applicable inside the vacuum as in the open room. On the use of more refined methods of weighing, however, the difference became apparent.

Application of the Formula.

We now come naturally to the consideration of the question, How far can a formula be used practically for obtaining the correct evaporation from a water surface by calculation from observations of temperature, wind and humidity? The writer is led to believe, from a large number of applications, that if the data are taken with sufficient accuracy and frequency, there is little doubt but that a very exact result may be reached. It will not do, however, to take the velocity of the wind at some little distance from the evaporating surface, or at any considerable height above it. During the season of 1885 monthly sheets were kept



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of all the meteorological data which it was thought could be of any use in throwing light upon the subject of evaporation. These included continuous records of wind velocity. The anemometer, however, was located 30.5 feet above the water. After some investigation it was found that the velocity of the wind was too great, and some experiments were made to establish the relation between the velocity at the surface of the water and at the anemometer.

It was found tha the former was about one-third the latter, but that it sometimes varied in an irregular manner.* Table No. 6 exhibits the difference between the actual evaporations as observed and the computed values, based on the supposition that the velocity of the wind exerted at the surface of Tank No. 1 was one-third that observed at the anemometer. The result is such as to give us confidence in the formula when applied to the hourly observations.

It is possible that the computed amount of evaporation for any given hour is nearer the true result than the observed value,† for the reason that there are difficulties in getting an exact measurement by hook gauge where the gauge has to be moved from tank to tank, as was done in the experiments recorded in this paper. The profiles of hourly evaporations (Plate LXXXI.) are plotted from the observed values, and also from those computed by the formula. The good results obtained from the computed evaporations from ice surfaces are shown on pages 613, 614.

Effect of the Sun.

Some writers having found a difference between the evaporation from a vessel exposed to the rays of the sun and one in the shade, other things being equal, the writer has exposed his evaporometers in such a way as to test the question. Experiments were made both with the same and with varying depths of water in the pans. Some of these were placed in the sun and others sheltered from its rays. They were carefully weighed every hour, and their temperatures taken every ten minutes. On applying the formula it was found to fit either case equally well. The velocity of

* See Jour. Scottish Met. Socy., Vol. V, pp. 103 and 348, and Nature, Vol. XXVII, pp. 432, 506.

† June 4th, 1886.—While this paper was passing through the press the author had several striking illustrations of the accuracy of the formula in checking results. On removing the weekly evaporation sheet June 1st, 1886, it was noticed that the amount recorded for the 25th of May was 0.4 inch. As showers had fallen during the night, and the temperature was not high, the writer thought some mistake had been made, but on applying the formula to the meteorological data, he found that the evaporation should have been 0.392 inch, practically the same as recorded by the instrument.

the wind was taken at the level of the pans. The following experiments are selected as fair averages of the series :

No. 1.—14 inches Deep, Exposed to Sun.				No. 2.—1 inch Deep, Placed in Shade.		
August 1st, 1885.	Mean Temp. *Degrees.*	Computed Evaporation. *Inches.*	Observed Evaporation. *Inches.*	Mean Temp. *Degrees.*	Computed Evaporation. *Inches.*	Observed Evaporation. *Inches.*
10 to 11 A.M.	82.2	.01	.02	77.7	.009	.008
11 " 12 "	85.6	.02	.02	76.6	.008	.011
12 " 1 P.M.	88.3	.03	.02	76.3	.008	.007
1 " 2 "	89.6	.04	.03	75.3	.009	.011
2 " 3 "	89.9	.04	.04	74.7	.009	.010
3 " 4 "	88.5	.03	.03	73.4	.008	.008
Totals....	.....	.17	.16	.....	.051	.055
Aug. 28th.	No. 1, in the Sun.			No. 2, in the Shade.		
10 to 11 A.M.	79.8	.018	.022	62.1	.006	.010
11 " 12 "	85.3	.024	.027	62.1	.006	.008
12 " 1 P.M.	85.4	.026	.026	63.2	.007	.010
1 " 2 "	85.7	.025	.030	64.9	.007	.007
2 " 3 "	83.5	.022	.023	65.8	.008	.012
3 " 4 "	78.2	.020	.022	65.6	.009	.011
4 " 5 "	70.9	.014	.013	64.5	.009	.010
Totals....	.....	.149	.163	.....	.052	.068

Influence of Depth on Evaporation.

Notwithstanding statements to the contrary, the depth of water has no other influence on evaporation than that due to its effects on the temperature of the surface. A number of experiments, under various conditions, were made in 1885, but they all tended to a uniform result on applying the formula.

The following example is here given, as it combines a variety of data. Two pans, 14.85 inches diameter, were placed side by side in the shade on July 28th. One contained 14 inches of water, the other 1 inch.

Observations were taken from 8 A.M. to 6 P.M., according to the same plan as in previous experiments. Attention is called to the range of temperature.

No. 1.—14 Inches Deep, in Sun.				No. 2.—1 Inch Deep, in Shade.		
July 28th, 1885.	Mean Temp.	Computed Evaporation.	Observed Evaporation.	Mean Temp.	Computed Evaporation.	Observed Evaporation.
8 to 9 A.M.	75.5	.008	.010	84.2	.015	.020
9 " 10 "	80.3	.013	.005	89.9	.023	.025
10 " 11 "	84.5	.022	.025	91.4	.032	.036
11 " 12 "	87.0	.029	.030	89.3	.032	.038
12 " 1 P.M.	88.8	.038	.060	87.1	.035	.043
1 " 2 "	89.4	.040	.040	85.8	.033	.036
2 " 3 "	89.7	.043	.030	83.9	.032	.037
3 " 4 "	89.9	.046	.040	82.0	.029	.032
4 " 5 "	88.9	.044	.050	78.5	.023	.023
5 " 6 "	87.3	.033	.020	75.6	.014	.016
Totals....	.....	.316	.310	.....	.268	.306

At 9.30 P.M. observations were taken which showed the deep pan to have lost 12.5 degrees since 6 P.M., while the shallow pan lost 16.1 degrees, leaving the former at 74.8 degrees, and the latter at 59.5 degrees. The observed evaporation during this interval was .050 inch from No. 1, the computed amount being .067 inch, while from No. 2, the observed evaporation was .015 inch, the computed value, .021 inch. The next morning, July 29th, at 7 A.M., the temperature of pan No. 1 was 68.2, and of No. 2, 69.6. Observations of the wet and dry bulb, and of the wind, gave the data for figuring the computed values. The observed evaporation from No. 1 during the night was .090 inch, the computed .070; of No. 2, the observed evaporation was .006 inch, and the computed .018, but the latter difference is fully accounted for by the following facts:

The shallow pan, from an early hour, say 5 A.M., had been gaining rapidly in temperature. Had an intermediate observation been taken, the .018 inch would undoubtedly have been very much reduced. In addition to this, the temperature of the shallow pan at 9.30 P.M. was slightly below the dew point, so that it must have robbed the air of some of its moisture during the night.

Other Experiments.

The most comprehensive investigation of the law of natural evaporation is included in two articles by Edward Stelling, published among the papers of the St. Petersburg Academy of Sciences.

The first of these articles is entitled "Upon the Dependence of the Evaporation of Water upon its Temperature, and upon the Humidity and Movement of the Air." It was read September 29th, 1881.

The discussion was founded upon experiments made by F. Dohrandt with a Wild evaporometer and before the improvement made in a floating pan, to which allusion will be made. The observations were taken at Nukuss, from May to October, and comprised notes on the temperature of the water in the sun and in the shade, twelve times a day, at every even numbered hour, with other meteorological data.

The writer is unable, without a more precise knowledge of the methods of making the experiments, to determine as to their accuracy. In this connection it is evident that the form of evaporating dish makes no difference in the results where the laws governing evaporation alone are sought, provided the data are properly collected.

Stelling discusses Soldner's* formula which allows for the barometric pressure, but concludes that the barometer may be neglected. He then analyses Weilenman's † formula which allows for the wind. This formula will not be given, as it is founded on several incorrect assumptions, among them that the temperature of the water corresponds to that of the wet bulb. Stelling's work is superior to all of these, particularly in his method of treating the forces of vapor. His formula, using the notation of this paper, is as follows:

$$E = A \Sigma (V - v) + B \Sigma (V - v) W.$$

This formula is the same in principle as the one adopted by the writer for his working formula. The constants A and B have been replaced by numerical values corresponding to the writer's experiments.

No pains were spared by Stelling in the use of least squares and other laborious mathematical computations to arrive at the truth, yet, after all, he is forced to use constants varying with the different months of the year, and in other ways his formula seems defective as expressing a definite law. In fact Stelling's patient investigations seem to be more those of an accomplished scholar struggling with a somewhat imperfect mass of data, than those of an original experimenter.

The second article, read December 22d, 1881, is entitled "On the Determination of the Absolute Amount of Evaporation from an Open

* Probably $\frac{dv}{dz} = \frac{A(S-s)}{b}$ See Gilbert's Annalen der Physik, B. XVII.

† A. Weilenman's "Die Verdunstung des Wassers."

Water Surface." This paper is based on observations made at Pawlowsk Observatory, near St. Petersburg. A floating atmometer was used here in 1878, and certain improvements were made in 1879.

Before the changes, the difference noted between the temperature in the floating instrument and the pool water outside was sometimes as much as 10 degrees C., and amounted in the monthly average to 3 degrees C. The metal bottom came in contact with an air space instead of being washed by the water outside; the latter condition was accomplished by the changes shown by the cut accompanying the article. The temperatures were then brought nearly to an agreement. After an elaborate mathematical analysis, Stelling came to the conclusion, that considering all the uncertainties of the case, the instrument represents almost without correction the evaporation from the surface of the pool. This floating vessel was a shallow pan 357.2 mm. diameter, and having an area therefore of 1 000 cm.^{2}. The thermometer was placed near the bottom.

PART II.

Discussion of Observations on Natural Evaporation.

In 1876, the writer began a series of observations on the evaporation from two floating tanks in the center of Chestnut Hill Reservoir. This body of water, which forms the largest distributing reservoir of the City of Boston's water supply, covers an area of 123½ acres, and is in the form of two basins. The larger, or "Bradlee basin," in which the experiments were principally made, covers an area of 85 acres. The depth of water near the center, where the tanks were located, is about 20 feet. The surface is 129 feet above mean sea level. A large raft floated the tanks and it was moored at one end to an anchor around which it could swing freely with the wind. One of the tanks was of wood covered with copper. It was 2 feet square and the water was kept about 1½ feet in depth. The other tank was a simple tin vessel about 1 foot in diameter and 2 feet deep. They were both kept as full as practicable, and immersed so that the level of the water inside and outside was about the same. A record was kept each morning of the heights of the water by means of a hook gauge, an instrument so familiar to engineers that no description is necessary. At the same time the temperatures of the water were taken in the tanks and reservoir, together with a reading of the wet and dry bulbs for humidity of the

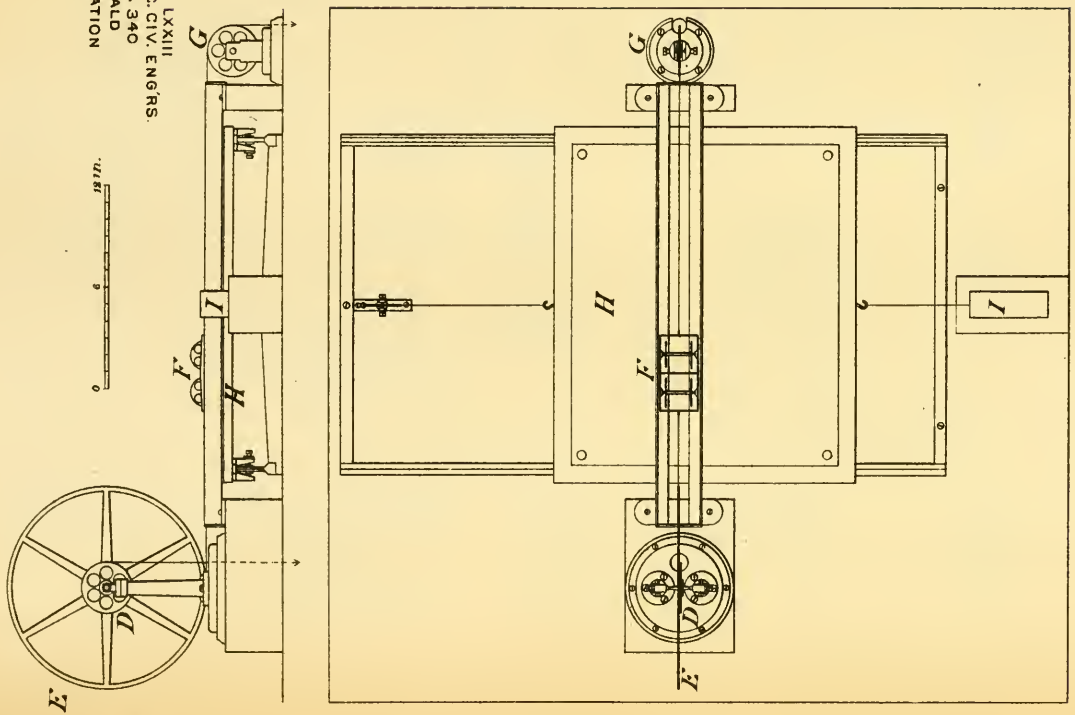
air. These observations were maintained until 1882, during the seasons when the water was not covered with ice.

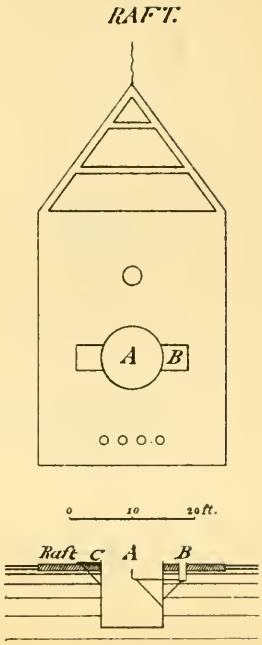
Subsequent observations, taken during every hour of the day and night, led the writer to infer that, owing to the varying temperatures of the water from hour to hour in the tanks as compared with the reservoir, and the varying march of these changes according to the month of the year, little dependence could be placed on the value of the results for application under other conditions unless some relation could be traced by more perfect observations. Accordingly an entirely different apparatus was designed late in the season of 1884 to plot a continuous profile of evaporation upon a sheet of paper. The velocity of the wind and the temperature of the air were also recorded automatically, and the mean humidity secured by readings at 7 A.M., 2 P.M. and 9 P.M.

Plates LXXIII and LXXIV, and the photograph, Plate LXXV, will give a complete idea of the apparatus on the raft, but some description seems necessary. The raft, represented on the right-hand side of Plate LXXIII, was 20 by 40 feet, and so built as to give considerable lateral and longitudinal stiffness. Its surface, which was boarded over, floated about two inches above the water. The front end was left open in a series of breakwaters in which the waves could expend their force. Spray flash-boards were added at the extreme outer end. In the center of the raft the tank *A*, 10 feet in diameter and 10 feet deep, was immersed, This tank was made of staves of wood, spaced 1 inch apart, excepting where the hoops were located, so as to give free access for the outer water to the thin copper lining inside. Many holes were bored in the wooden bottom for the same purpose. It was expected that this would keep the water inside at the same, or nearly the same, temperature as that outside, but this was sometimes far from being the case. On one occasion the writer observed a difference of 10 degrees F. A smaller tank, *B*, containing a 16-inch float, was bracketed to one side of the tank, and connected with its center by a pipe which was throttled by a brass plate with a small hole, so that wave motions were not communicated to the float. The recording apparatus was on the same bracket with the float chamber, and immediately over it. A light cover of tin protected it from the weather.

As finally adjusted, the weight of a man stepping suddenly upon the raft carried the pencil 0.25 inch from the profile, and on his stepping off, the pencil returned to its former position. These perpendicular marks

Apparatus for recording Evaporation.





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Details of Recording Apparatus.

PLATE LXXIV.
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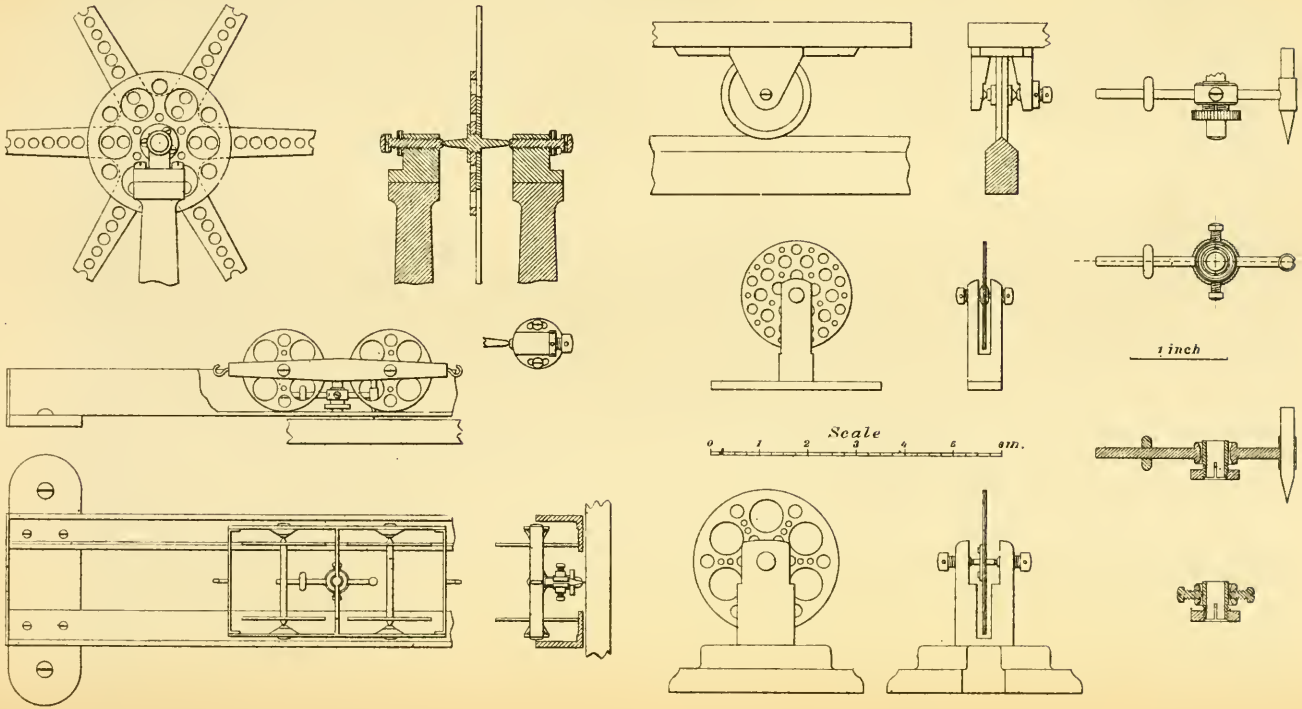
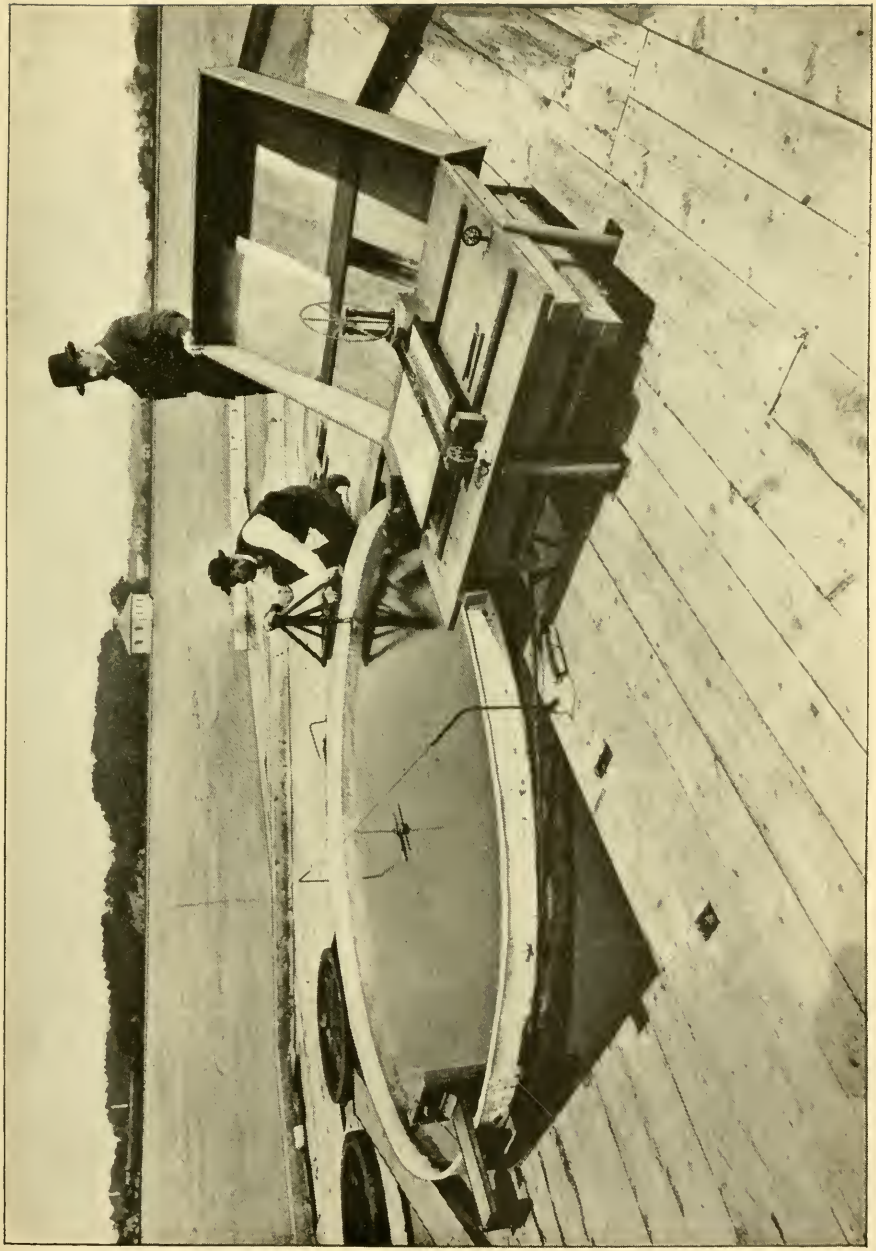




on the diagram could be readily distinguished from the profile of evaporation, and in no way interfered with the record, on the contrary, they served to check any unlawful visits to the raft.

The Recording Apparatus.

A plan and side elevation of the recording apparatus are given on Plate LXXIII. The wheel *D*, 3 inches in diameter, was connected directly with the float by a fine wire. The large wheel *E*, 1 foot in diameter, was rigidly connected with *D*, and communicated the movements of the float, magnified four times, to the small truck *F*, which was counterweighted at the end of the wire passing over the wheel *G*. The truck, running in a V-shaped grooved track, carried a pen which left its record on the diagram spread on the drawing board *H*. This board was pulled over a track at right angles with the movements of the truck by a clock movement *I*. Every inch of vertical movement of the float made 4 inches of movement on the diagram, so that hundredths of an inch could easily be read. The wheels were all mounted on agate bearings, and were nicely balanced. The whole friction of the apparatus was less than 0.01 of an inch, as read on the diagram. The details of this delicate piece of machinery are given on Plate LXXIV, and one of the diagrams covering a week's time, photographed on a reduced scale, is given on Plate LXXVI.

By means of these continuous profiles, all the changes taking place on the surface of the large tank were accurately recorded where they could be examined at leisure, and in comparison with the meteorological data. The tank was not only a self-recording evaporometer, but was also a self-recording rain gauge. An independent rain gauge of excellent pattern was, however, kept on the raft, and also others on the land adjoining the reservoir. It became evident from these records that evaporation may amount to a measurable quantity, even during a rain storm. Indeed, under certain unusual conditions, the writer has observed clouds of vapor in a visible form rising from pools of water while rain was falling. Maximum and minimum recording thermometers were placed both in the tank and the water of the reservoir. These were attached to tin floats, 2 inches in diameter and 6 feet deep, so that the bulbs were just beneath the surface of the water. These glasses were read and set daily. Six smaller tanks of various forms and depths were also kept on the raft from time to time, and a record of

their temperatures taken at about the hours of maximum and minimum temperatures, viz., 7 A.M. and 3 P.M. Their position on the raft is designated by the small circles.*

Temperatures.

In order to insure accuracy in the temperature comparisons, considerable study was given to this branch of the subject. It was finally decided to use for all hourly observations a thermometer made by Baudin, Paris, and for all other observations nine thermometers by Alvergniat, Paris, which had been made some time previously. These were all tested for different points in the scale, through the courtesy of Prof. Holman, at the Massachusetts Institute of Technology, and their corrections tabulated. The Baudin instrument was graduated to 0.2 degrees C., and could be easily read to 0.1 degree. The maximum and minimum thermometers were made by Green, of New York. Their errors were tabulated. All of the centigrade readings have been converted into Fahrenheit.†

Other Instruments.

An electrical recording anemometer was kept on the shore of the reservoir. The cups were at grade 154.5, or 30.5 feet above the water. The velocity of the wind where the anemometer was placed was found to represent generally three times that at the surface of the water (see page 591). In a standard shelter, and excellently exposed, were a Green psychrometer, a Richard Frères thermograph, and maximum and minimum thermometers. Humidity observations founded on readings of the dry and wet bulbs are to be accepted with considerable caution. From many comparative readings made for the purpose, the writer is led to believe that there is hardly any instrument in common use which is liable to so many errors. The formulas on which the tables are based are founded on assumptions which are more or less correct, but the principal sources

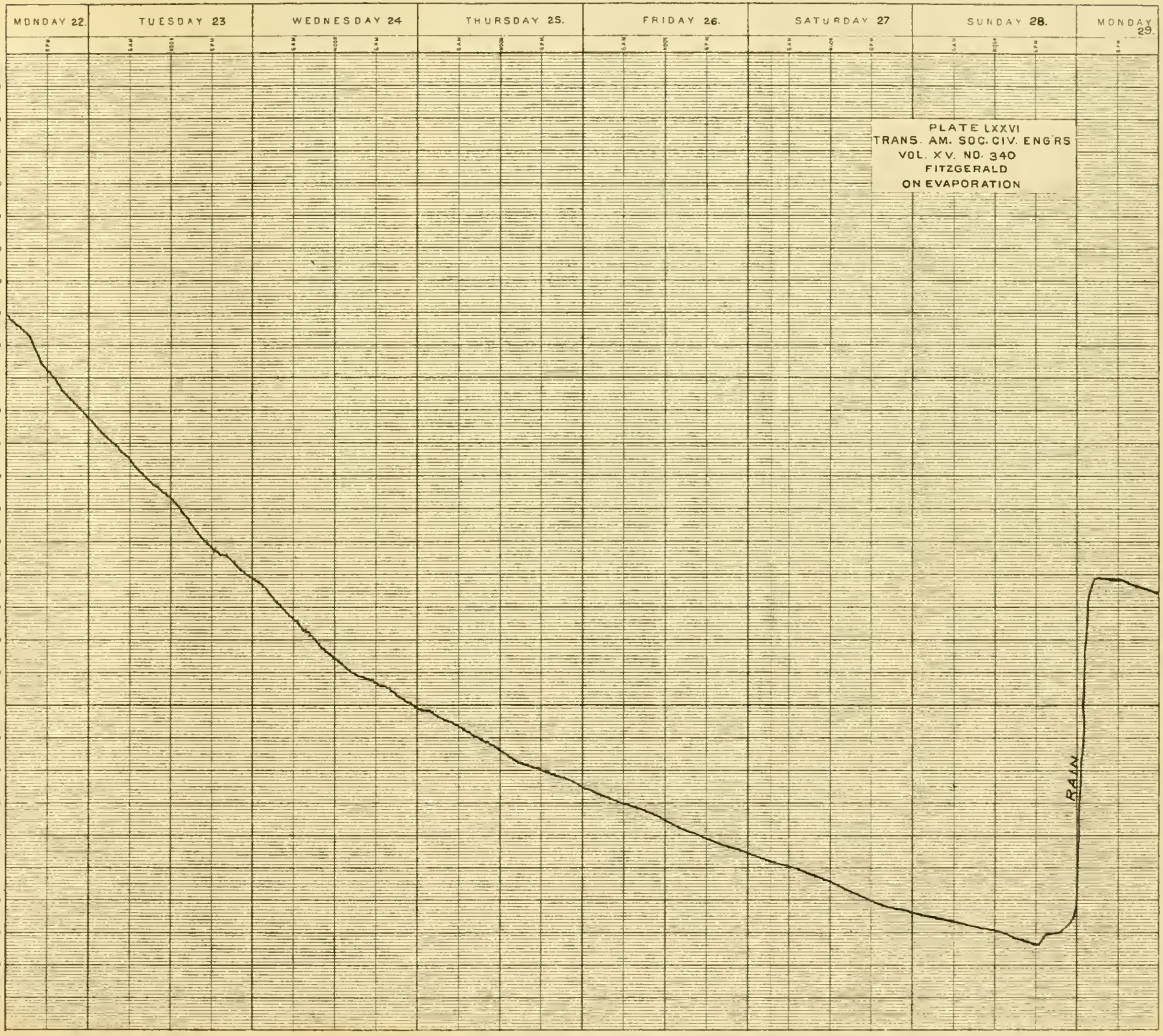
* The following are the dimensions of all the tanks:

Tank No. 1,	copper,	10 feet	diameter	10 feet deep.	
" " 2,	tin,	1 "	"	8 " "	
" " 3,	"	1 "	"	2 " "	
" " 4,	copper,	1 "	"	2 " "	
" " 5,	tin,	1 "	"	6 inches deep.	Painted white.
" " 6,	"	1 "	"	6 " "	" dark green.
" " 7,	"	3 "	"	6 " "	

† The folly of the Fahrenheit scale has been recently shown in a paper read before this Society by Mr. Fred. Brooks, M. Am. Soc. C. E. (No. 333. May, 1886.)

DIAGRAM OF EVAPORATION FOR WEEK ENDING JUNE 29TH 1885.

By Continuous Recording Apparatus designed by Desmond FitzGerald to determine evaporation from a water surface. Experiment conducted at Chestnut Hill Reservoir Boston Water Works



of error arise from differences of exposure, lack of ventilation and the use of round bulb glasses. Where the air is not moving across the wet bulb at a proper speed, a fan should be used. Below freezing the observations are practically worthless. There is little doubt that a condensing hygrometer of any good form is far more trustworthy. Such an instrument will give the dew point at once from which the force of vapor and the relative humidity, if it is desired, may be easily computed. During a certain portion of the summer of 1885, two sets of maximum and minimum thermometers were kept alternately in Tank No. 1 and in the reservoir. There are numerous errors to which these instruments are liable, and the duplicate set acted as a check. In addition, readings were usually taken at about the hours of maximum and minimum temperature, viz., 7 A.M. and 3 P.M., with the Baudin standard. The readings of all these instruments are compared in Table No. 1.

Finally, all the meteorological data were collected on monthly sheets, from which information of different kinds could be obtained as needed. From these sheets Table No. 2 was collated. This table shows only the mean daily temperature of the surfaces of the reservoir and of the several tanks, and the daily evaporation from the tanks.

It must be borne in mind that these means do not give us an idea of the range of temperature during the days given. A small body of water may give exactly the same mean as a larger one, and yet pass through a very different scale in the 24 hours. To speak accurately, evaporation does not depend upon the means, but upon the conditions from moment to moment.

Hourly Observations.

To determine how far the changes between small fractions of a day affected the means, a series of hourly observations was made on at least one day in every month. These are embodied in Table No. 3, and will be found to possess particular value. As will be noticed, in July a three days' period of continuous observations was secured. The weather was fine during nearly the whole time. The summer nights are rarely accompanied by much wind, and special arrangements can be easily made for taking the temperatures to 0.1 degree as readily as by day. In observing water temperatures it was made a uniform rule to hold the glass as nearly horizontal as convenient with the long bulbs of the

French makers just beneath and as near the surface as possible. When the sun was shining the bulb was shaded with the hand, though this was found to make no material difference in the readings.

The profiles, Plates LXXVII and LXXVIII, exhibit graphically the temperature changes at the surfaces of the reservoir and tanks at all hours of the day and night for short periods at different times.

In the early part of the summer the large tank was sometimes so much hotter than the reservoir, that the writer believed important corrections would have to be made for temperature, but as the season advanced these differences grew less and less, and in the autumn the reservoir become warmer than the tank as often as otherwise.

While these daily and hourly data were accumulating, the experiments already described were made to determine the exact laws governing evaporation. The general result was to lead to a close scrutiny of the temperatures of the evaporating surfaces, of the force of vapor in the air, and of the velocity of the wind, which were found to be the three important factors.

Some Results.

It became evident, from an inspection of the continuous diagrams, that the maximum evaporations are not recorded on the hottest days in the year. A high temperature of the air means commonly a considerable force of vapor present in the air, so that $(V-v)$ is not as great on such a day as when the air is cool and of low vapor carrying capacity. When a body of water is heated to a high temperature, and the air becomes cooler, the temperature of the water does not change much, and V is still large, while v will be much reduced, so that $(V-v)$ becomes larger and evaporation proceeds more rapidly. Thus on a cold day, preceded by warm weather, we may look for the maximum evaporation. Such we find, by many observations, to be the case. On June 23d, 1885,* the greatest evaporation that the writer has ever recorded occurred at Chestnut Hill Reservoir, viz.: 0.57 inch from Tank No. 1, 0.64 inch from Tank No. 2, and 0.58 inch from Tank No. 3. The mean temperature of the water in the reservoir for this day was 70.7 degrees; in Tank No. 1, 69.8, in Tank No. 2, 70.8; and in Tank No. 3, 69.9 degrees. Judging by the comparative data, the evaporation from the

*A day in the Chestnut Hill Reservoir experiments was always taken from 5 P.M. of the preceding day to 5 P.M. of the date given, and is so understood throughout this paper.

reservoir must have been nearer 0.64 inch than 0.57 inch. The mean temperature of the air was 60.2 degrees, about 10 degrees less than on the preceding days. The force of vapor in the air, largely owing to its low temperature, was only 0.313 inch. The velocity of the wind averaged 12.3 miles per hour 30 feet above the water, a combination of circumstances that favored a very large evaporation. The results for the whole week ending June 29th were so remarkable, that the diagram from the recording apparatus has been selected from the other sheets for reproduction in this paper. (See Plate LXXVI.) It is doubtful if the evaporation from a natural water surface in a single day in Massachusetts will ever much exceed this amount. The maximum daily evaporation in Arles, France, from M. Salle's experiments (see page 622) was 0.56 inch on July 31st, 1878.

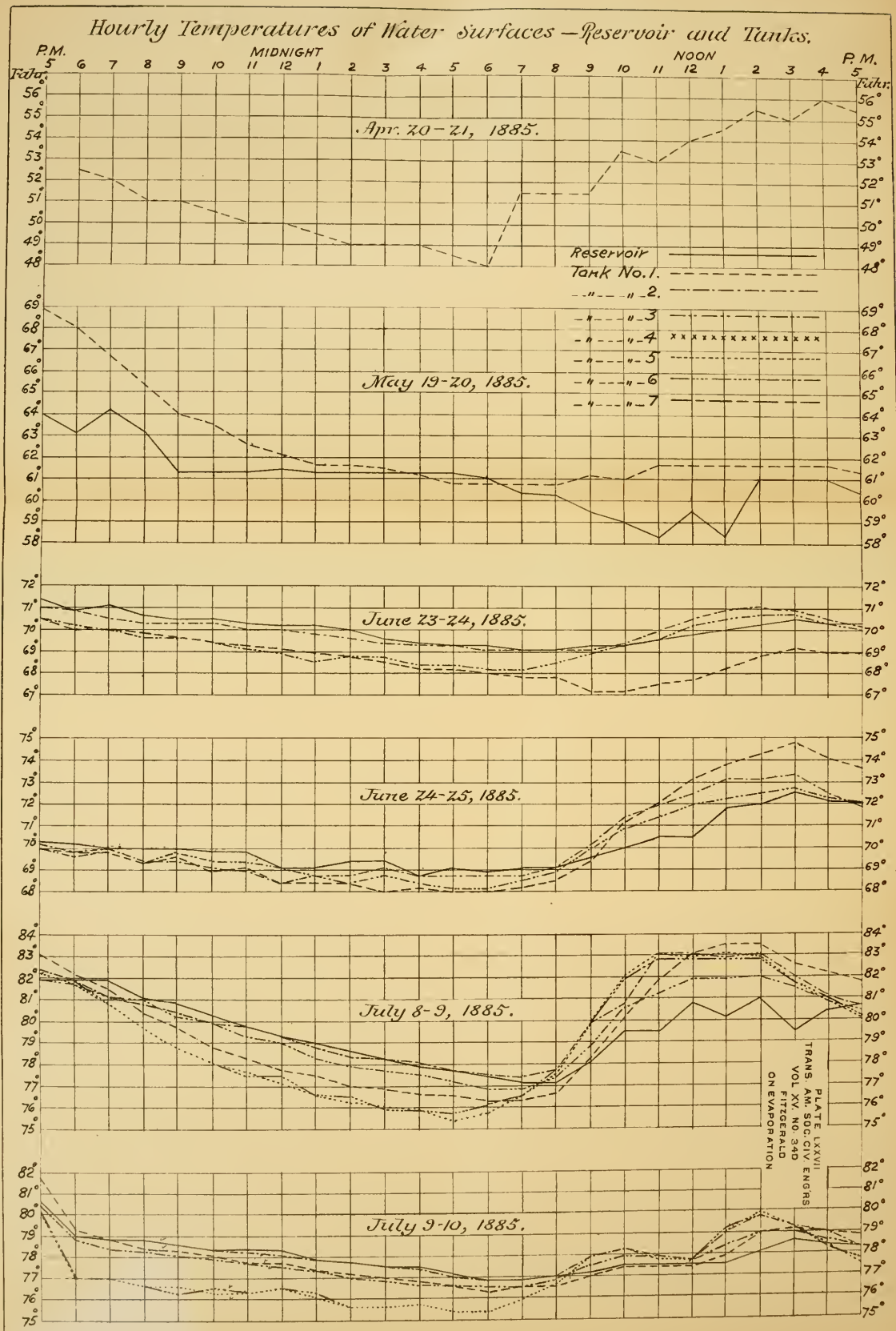
The evaporation for the six days after noon of the 22d above alluded to was so extraordinary, that its effects on vegetation were noticed throughout the surrounding country. Fortunately, hourly observations were secured for 48 continuous hours during this period, which will be found in Table No. 3.

On December 19th, 1885, the writer was passing the reservoir, when his attention was called to clouds of vapor rising from the water. A strong wind was blowing these clouds across the road, and it was observed that evaporation was proceeding at such a rate as to obscure more than half of the sheet of water. The temperature of the air was 20 degrees below the freezing point, viz.: 12 degrees F. The temperature of the water, both at the surface and at a depth of 10 feet, had been 38 degrees for some time owing to warm weather. At the time of the observation it stood at 37 degrees. The vapor in the air was = 0.030 inch. Here we have also favorable conditions for the rapid formation of vapor, which quickly filled the cold air with more than it could carry in an invisible form. The wind was blowing at the surface of the water at a rate of at least 4 miles per hour by estimation.

The writer is satisfied that the rate of evaporation under the above conditions must have been about 0.23 inch per day. (See formula, page 589.) Undoubtedly this is a very unusual state of things, but when evaporation during the winter months is so often placed at 0, this case is worth remembering.

Another important result of the hourly observations and of the re-

corded diagrams, was the development of the fact that the evaporation from a large water surface is nearly alike during the day and night. Such is undoubtedly the fact, and must be apparent after a due consideration of the results in the tables and a study of the theoretical side of the question. During the principal part of the season of 1885, observations were taken of the tanks night and morning in such a way as to give full information on this point. A glance at the profiles of hourly temperatures, Plates LXXVII and LXXVIII, will show that there is not very much difference in mean water temperatures between the day and night hours. It takes the greater part of the day for the water to regain the heat which it loses during the night In Table No. 3 the evaporation of the night has been separated from the day for the days when hourly observations were taken, and when little doubt could be thrown on the mean temperatures of the water. In comparing the day with the night evaporations it must be borne in mind that the velocity of the wind is generally greater in the middle of the day than at other times, and so has its influence on the amount of evaporation, but on days when there is little wind, or wind equally distributed throughout the 24 hours, the evaporation is practically the same day and night. Of course, the smaller the amount of water exposed the less will the rule apply, for the more nearly will its temperature follow the temperature of the air. This is the reason for the great errors in ordinary experiments on evaporation made from small atmometers above ground, whose sides are fully exposed to the air and sun. With such instruments the evaporation for the day will be very great, and that during the night correspondingly small, in no way following the evaporation from a large pond of water. In shallow pans, immersed in the body of a stream or pond of water, as was the case with Tanks Nos. 5, 6 and 7, which were only 6 inches deep, the total evaporation in a long period does not differ very much from that from a large body of water, for the reason that the differences generally happen to balance or may balance in a season, some months showing larger and others smaller results than the deeper body of water. It has been found by the writer that the evaporation from a considerable body of water may be greater on some particular days, even during midsummer, than from a shallow pool. When the air is cooling rapidly, its influence will be felt very much sooner in the latter than in the former case. Again, it is possible that on an extremely hot day, the loss from a large body of water may be greater than from a


Hourly Temperatures of Water Surfaces—Reservoir and Tanks.
P.M.
MIDNIGHT
NOON
P.M.
Fahr.
Apr. 20-21, 1885.
May 19-20, 1885.
June 23-24, 1885.
June 24-25, 1885.
July 8-9, 1885.
July 9-10, 1885.
Reservoir
Tank No. 1.
" " 2.
" " 3
" " 4
" " 5
" " 6
" " 7
PLATE LXXVII
TRANS. AM. SOC. CIV. ENGRS.
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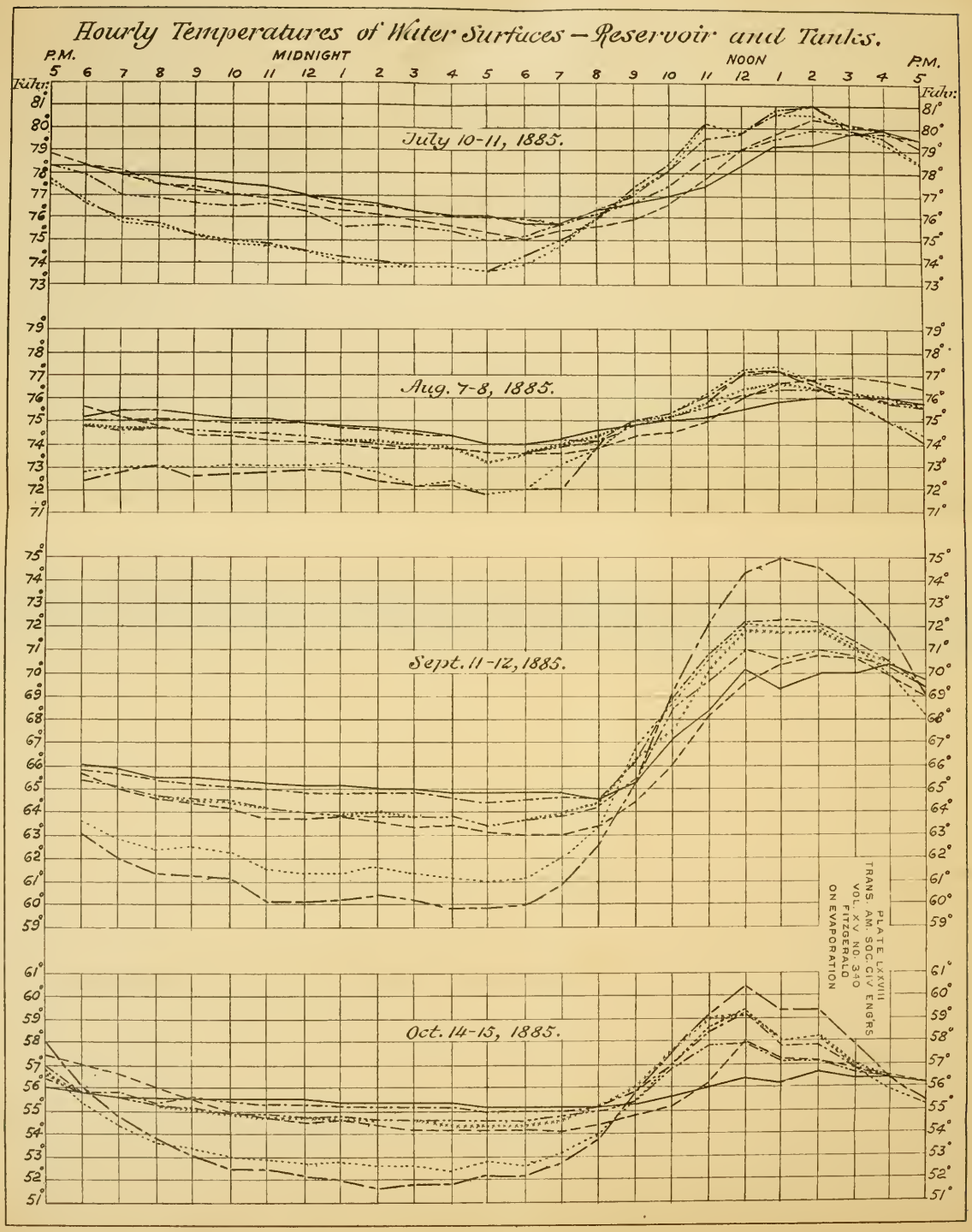
FITZGERALD
ON EVAPORATION


Hourly Temperatures of Water Surfaces — Reservoir and Tanks.
P.M.
MIDNIGHT
NOON
P.M.
5 6 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10 11 12 1 2 3 4 5
Fahr.
July 10-11, 1885.
Aug. 7-8, 1885.
Sept. 11-12, 1885.
Oct. 14-15, 1885.
PLATE LXXVII
TRANS. AM. SOC. CIV. ENG'RS
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ON EVAPORATION

shallow pool, from the fact, which the writer has several times observed, that the maximum temperature of the reservoir may not occur until very late in the afternoon, say 6 P.M., long after the shallow tank had begun to part with heat.

The question is often asked, "What is the highest temperature that the surface of a reservoir ever attains?" At 5 P.M. on July 18th, 1885, the temperature of the water in Chestnut Hill Reservoir was 82.2 degrees at the surface, and practically the same to a depth of 5 feet. At 7 feet it was 80.5 degrees; at 8 feet, 79.0 degrees; at 9 feet, 77.5 degrees; at 10 feet, 76.0. At 7 A.M. the same day, the surface was 78.4 degrees. On September 10th, 1884, the writer found the temperature of the surface of the same reservoir at 86.0 degrees, taken with a Green thermometer, stem graduated, whose error was not known, but probably not far wrong. This was during a period of extraordinary heat. The temperature of the water in a copper rain gauge, covered, was found to be 116 degrees at the same time. On account of the interest which they possess as illustrating some of the above remarks, the hourly temperatures of the reservoir and of all the tanks is here given for July 18th, 1885, from 7 A.M. to 6 P.M. It will be noticed that the shallow pans, Nos. 5 and 6, attained their maximum at 1 P.M., viz., 82.8 degrees, and that at 6 P.M., when the reservoir had lost but 0.5 degree, they had lost 2.9 degrees.

JULY 18TH, 1885.

	7 A.M.	8 A.M.	9 A.M.	10 A.M.	11 A.M.	12 M.	1 P.M.	2 P.M.	3 P.M.	4 P.M.	5 P.M.	6 P.M.
Reservoir	78.4	79.5	79.3	79.9	80.8	80.6	81.1	81.3	81.7	81.9	82.2	81.7
No. 1	77.4	78.8	79.7	80.2	81.1	82.2	82.9	83.1	83.1	82 8	82.4	81.9
" 2	78.4	79.9	80.6	80.8	81.9	81.9	82.6	82.6	82.4	81.9	81.5	81.3
" 3	78.1	79.3	80.1	80.2	81.1	81.5	81.6	81.9	82.0	81.9	81.5	81.3
" 5	78.3	80.1	80.8	81.1	82.2	82.2	82.8	82.6	82.4	81.3	81.5	79.9
" 6	78.1	80.2	80.8	81.0	82.2	82.4	82.8	82.6	82.4	81.5	81.3	79.9

In the course of the whole season, Tank No. 1 gave about 8 per cent. less evaporation than Tank No. 3. This occurred repeatedly when the temperatures were the same, and it was also the case when the temperatures were taken hourly, when it would seem that the mean temperatures could not be far from correct. The writer is unable to say certainly to

what the difference was due, but is inclined to the opinion that capillary attraction on the inside of the small tanks increased the evaporating area.

Monthly Results.

We now return to the consideration of the monthly evaporations observed at Chestnut Hill Reservoir during six years between 1876 and 1886, and to the corrections, if any, to be applied to the wooden box or tin vessel. These results were published in the Reports of the Boston Water Board from year to year, but a careful review of the original notes, and a new analysis in the light of greater experience, has led to the detection of certain errors, mostly small in amount, which will account for the difference between the values now assumed for certain months and those already published. The labor of this analysis was very great, as every observation during the whole period had to be critically examined.

The evaporations from the wooden box and from the 10-foot tank were finally adopted as representing the evaporation from the reservoir without any further corrections for temperature.

The reasons for this were numerous, but principally as follows: The evaporation from the wooden box was from 7 to 30 per cent. less than that from the tin vessel, and at Beacon Hill Reservoir, which will be referred to immediately, was found to correspond very closely with the measured evaporation from the reservoir. The writer concluded from his experiments in 1885, that although the mean temperatures were about the same, the surface of the reservoir was generally cooler during the middle of the day, when there was most wind, than Tank No. 1, and notably less than the smaller tanks. As far as temperature was concerned, therefore, a slight correction in the way of subtraction should be made from the large tank, but it is undoubtedly true that the reservoir surface had a better exposure to the wind, which would have required a correction in the opposite direction.

The table at head of the next page will show the mean monthly temperatures in Tank No. 1, and in the reservoir for 1885.

During the months of August and September, the Lawrence basin was shut off from the city's supply, for the purpose of measuring the actual evaporation from its surface while the other experiments were in progress. This basin has an area of 37½ acres. On the days when there was little difference in head between the two basins, the measured evaporations agreed very well with those from Tank No. 1. From

	No. of Days.	Reservoir. Degrees F.	Tank No. 1. Degrees F.
May	13	61.2	62.8
June	29	69.5	70.4
July	31	77.3	77.2
August	31	74.4	74.4
September	30	66.0	66.0
October	31	57.0	57.0

September 1st to 22d, when there was little difference of head, the evaporation from the reservoir was found to be 3.83 inches, and from the tank, 3.87 inches.

It must be remembered, however, that as already mentioned, a true idea of evaporation cannot be arrived at by an examination of means, but the writer believes the means of the wooden box and reservoir temperatures, considered through all the varying seasons, to represent, when examined in detail, a pretty fair correspondence.

It is of course doubtful if an exact result can ever be reached in the case of a large reservoir of water, certainly never until it can be proved to be water-tight both at sides and bottom, and experimented on as a whole, and even then the result would only apply to that particular sheet of water. Another, though but a short distance from it, would certainly vary somewhat from difference of situation and exposure to the air, sun and wind.

Means.

	Box.							Tin Vessel.						
	May.	June.	July.	Aug.	Sep.	Oct.	Nov.	May.	June.	July.	Aug.	Sep.	Oct.	Nov.
1876	....	5.44	7.50	6.21	3.48	3.12	0.66	....	5.71	8.82	7.94	5.23	4.57	1.13
1877*	4.05	5.68	4.82	4.40	4.08	2.51	....	4.35	6.45	6.02	5.55	5.83	3.59	....
1878	4.14	5.26	6.04	4.33	4.04	3.52	....	4.86	5.84	8.19	5.18	5.40	4.66	1.72
1879	5.89	5.32	6.41	5.23	3.80	2.99	....	6.28	6.36	7.75	6.72	5.33	4.36	1.75
1880	5.22	6.46	5.82	5.34	4.04	2.79	2.60	5.21	7.79	7.24	6.78	5.64	4.04	2.50
1885	3.77	7.01	7.09	7.41	5.13	2.79	....	3.97	7.86	7.99	6.87	5.64	3.39	....
Means	4.61	5.86	6.28	5.49	4.09	2.95	1.63	4.93	6.67	7.67	6.50	5.51	4.10	1.77

* Supplied by calculation from the tin vessel observations.

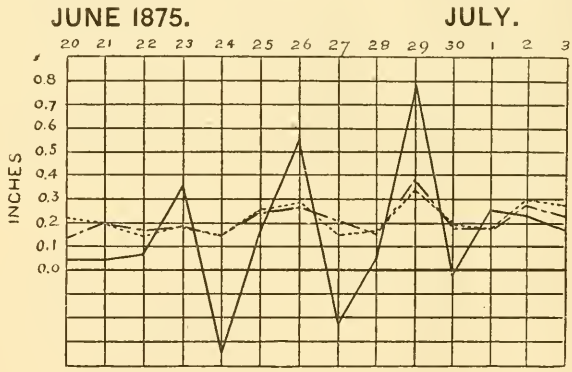
Beacon Hill Reservoir.

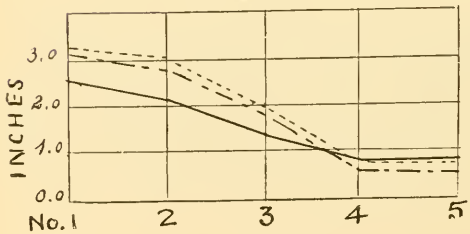
On May, 1874, evaporation experiments were started at this reservoir under the direction of the City Engineer, Mr. J. P. Davis, M. Am. Soc. C. E. The Beacon Hill Reservoir was a stone structure built on arches and raised above the surface of the ground. It was in the center of the city, surrounded by buildings which were generally higher than the reservoir surface. It was somewhat less than an acre in area and about 11 feet deep. The evaporation was measured in three ways: 1st. From the reservoir surface; 2d. From a wooden floating-box; and 3d. From a tin vessel.

All of the original notes were placed in the hands of the writer, and have been submitted to a careful examination.

The values as finally adopted for the records from this reservoir differ slightly from those published in the Water Board Reports, but are believed to be more correct. There were innumerable difficulties in the way of arriving at the true evaporation from this reservoir.

The notes show such irregularities as to warrant the rejection of a large portion of them. Every attempt was made to ascertain the cause of the daily fluctuations in the gauge-box. The head in the reservoir





1875.

No. 1—May 22 to June 7.
" 2—June 19 to July 3.
" 3—July 7 to 15.
" 4—October 17 to 26.
" 5—Oct. 31 to Nov. 9.

being always considerably greater than that in the mains outside, precluded the idea of a leak through the gates as explaining the difficulty. The reservoir was filled by a small pipe connecting with the high service. As the structure has since been torn down, no opportunity for further investigation has presented itself.

On the whole, the writer is inclined to believe the wind to be the cause of the trouble, as he has frequently noticed the water to be piled up on one side of a reservoir, even in a moderate wind, and sufficiently so to affect the readings in a gauge-box. A fair sample of the daily evaporation record from the reservoir surface is plotted on the preceding profile, and compared with the evaporation from the floating evaporometers, and in the second profile the means for several dry periods are plotted, which show a better result. Accordingly, the monthly means from the reservoir have been admitted, except in instances where they were obviously wrong.

Taking first the records of the wooden box and tin vessel which were begun in 1875, we have the following figures for the monthly evaporation in inches.

It will be noticed that some values for the winter months are here for the first time secured. The ice was kept cut on two sides of the reservoir. Nearly all of the winter observations, however, were so untrustworthy, that they were rejected.

Box.	May.	June.	July.	Aug.	Sep.	Oct.	Nov.
1875.....	4.72	5.23	6.54	5.00	4.94	2.55	1.47
1876.....	4.79	5.15	7.33	.....	3.56	2.83	.....
1877.....	3.66	5.53	5.35	4.56	4.29	.....	.....
1878.....	3.65	4.58	6.08	4.31	3.58	2.49	.....
Mean.....	4.20	5.12	6.32	4.62	4.09	2.62	1.47

Tin.	May.	June.	July.	Aug.	Sep.	Oct.	Nov.
1875.....	4.63	5.51	7.15	5.72	5.82	2.93	1.75
1876.....	4.48	5.29	7.88	.....	4.80	3.75	.....
1877.....	3.96	6.05	5.98	5.29	5.57	.....	.....
1878.....	4.07	4.88	7.03	4.63	4.31	3.24	.....
Mean.....	4.28	5.43	7.01	5.21	5.12	3.31	1.75

From the Reservoir.		
January.....	0.65	1 year.
February.....	0.68	1 "
March	2.30	1 "
April.....	2.45	1 "
May.....	3.58	6 years.
June.....	4.23	5 "
July.....	6.34	5 "
August.....	4.85	4 "
September.....	4.34	5 "
October.....	2.77	4 "
November.....	1.80	3 "
December.....	0.79	3 "

Dry Periods.

The following tables show the evaporations both at Beacon Hill Reservoir and Chestnut Hill Reservoir during dry periods, when the observations were undisturbed by rain.

Beacon Hill Reservoir.

No.	1875.	No. of Days.	Res.	Box.	Tin.
1	May 22, June 7	16	2.63	3.13	3.33
2	June 19, July 3	14	2.15	2.91	3.04
3	July 7–15	8	1.42	1.79	1.96
4	October 17–26	9	0.73	0.63	0.78
5	October 31, November 9	9	0.94	0.64	0.91

Beacon Hill Reservoir.					Chestnut Hill Res.
1877.	No. of Days.	Res.	Box.	Tin.	Tin.
May 26, June 5	10	1.30	1.86	2.02	2.16
June 9–21	12	1.94	2.27	2.58	2.47
July 30, August 8	9	1.63	1.58	1.83	2.07
August 20–25	5	0.70	0.84	1.00	0.94
September 3–19	16	3.03	2.94	3.18	2.80
September 24–October 3	9	1.07	1.11	1.49	1.26

Beacon Hill Reservoir.					Chestnut Hill Reservoir.	
1878.	No. of Days.	Res.	Box.	Tin.	Box.	Tin.
May 17–30	13	1.49	1.79	1.93	2.10	2.09
June 1–8	7	1.20	1.33	1.42	1.46	1.59
June 24, July 9	15	2.82	3.34	3.87	3.69	4.04
July 12–20	8	1.68	1.68	2.04	1.63	1.97
August 12–19	7	1.04	1.03	1.17	1.06	1.17
" 26–31	5	0.64	0.79	0.97	0 80	1.05
September 14–26	12	2.08	1.96	2.42	1.85	2.50
" 30, October 9	9	0.74	0.99	1.31	1.07	1.49
October 16–23	7	0.75	0.63	0.81	0.74	0.95

Beacon Hill Reservoir.

1879.	No. of Days.	Res.	Pan.
May 21–31	10	2.13	2.63

CHESTNUT HILL RESERVOIR.—DRY PERIODS.

1885.	No. of Days.	Res.	Tank No. 1.		Tank No. 2.		Tank No. 3.		Tank No. 4.		Tank No. 5.		Tank No. 6.		Tank No. 7.	
		Mean Temp.	Mean Temp.	Evap.	Mean Temp.	Evap.	Mean Temp.	Evap.	Mean Temp.	Evap.	Mean Temp.	Evap.	Mean Temp.	Evap.	Mean Temp.	Evap.
June 9–28.....	20	71.0	72.0	5.32	....	....	71.1	6.03	....	....	....	....	....	....	....	....
" 13–28.....	16	72.3	73.2	4.17	72.6	4.73	72.4	4.84	....	....	....	....	....	....	....	....
July 15–28.....	14	79.2	79.3	3.48	79.5	3.96	79.1	4.02	....	....	78.9	3.94	78.9	3.87	....	....
Aug. 5–21.....	17	75.7	75.9	4.59	76.3	4.26	75.6	4.17	75.6	4.05	75.3	4.19	....	....	....	....
" 7–21.....	15	75.5	75.7	3.94	76.1	3.69	75.5	3.59	75.4	3.50	75.1	3.62	....	....	75.6	3.43
Sep. 11–22.....	12	66.8	66.9	1.99	67.4	2.36	66.4	2.28	66.9	2.30	65.8	2.16	....	....	66.3	2.03
" 25—Oct. 1...	7	63.1	63.2	0.76	63.8	1.02	63.0	1.01	63.4	0.99	62.3	0.90	....	....	63.2	0.91

Evaporation in Winter.

The evaporation in the winter after the middle of December is generally from a surface of snow or ice. The difficulties of measuring the loss of vapor in these months has led to too low an estimate of the result. The evaporation for three or four months of the year is commonly placed at zero.

During the winter of 1878–79, the writer designed an apparatus for measuring the evaporation from snow as it commonly rests on the earth or ice. It consisted of a metal-lined box, having an area of 1 732 square inches. This was filled to a depth of 9 inches with a mixture of sand, clay, loam, etc., and was sunk into a framework in the ground, within which it could be raised or lowered. A light form of track some distance over the box carried a truck, which was moved forward over the box when it was to be weighed. The box was kept filled with snow to its top as far as practicable, and the losses by evaporation were determined day and night by hanging a large scale beam on the truck and screwing up the box and scale through the center of the truck. One ounce in weight represented 0.001 of an inch in depth of water. The scale was sufficiently delicate in adjustment to obtain the true weight within five ounces.

Whatever filtered through the earth was caught in a pan and weighed separately. After the earth once became frozen, however, it was water-tight, and nothing went through it until the spring thaw, though several inches of water at times stood on the surface. The general result gave 0.02 inches per day for the winter average.

Many comparative experiments have been made from time to time at Chestnut Hill Reservoir between snow and ice evaporation, and it has been found that the evaporation from ice is nearly twice as rapid as from snow, that is to say in two atmometers, 14.85 inches in diameter, placed side by side and filled with snow and ice, both resting on scales, so that the loss of 1 ounce = 0.01 inch of water, the ice will lose twice as much weight as the snow in the same time.

From February 19th to February 25th, 1885, observations were taken on the loss from a cake of ice properly exposed to the air, and it was found to lose at the rate of 0.06 inch per day. On March 11th the same experiment was repeated and minutes kept, sometimes every hour, of the loss by weight. The records were maintained until March 27th.

This period gave an average of 0.04 inch per day. On February 24th, 1886, the writer found evaporation from an ice surface, with the wind at 12 miles an hour, proceeding at the rate of 0.2 inch per day. It is not probable that the above represents the exact evaporation from a large ice surface any more than the evaporation from a small evaporometer represents the true results from a large body of water. In order to get some comparative data on which to form an idea of the proper corrections, and whether the evaporations from ice followed the same laws as that from water, numerous experiments of a theoretical nature were made, and the general result was such as to lead the writer to believe that this is really the case as stated by Dalton.* Experiments, however, which fail to secure the exact temperature of the surface of the ice will be deficient, as were Dalton's, for the ice does not follow the temperature of the air any more than the water does. Furthermore, the temperature of the ice in the reservoir is very often entirely different from that in an experiment in the air some little distance above its surface, and without a large mass of water under it. In all the experiments made by the writer on the evaporation from ice, the following general methods have been adhered to, in order to secure accuracy of results. Cakes of ice have been uniformly trimmed to a diameter of 14.85 inches, and then fitted into the same pans illustrated in Plate LXX. The surfaces have then been planed to a perfect level, and exactly even with the tops of the pans. Any spare spaces on the side have then been filled with freezing water, and the pans placed upon Fairbanks' scales. To get the temperatures of the surface, thermometers have been sunk so that two-thirds of the bulb was below the surface of the ice, with the stem nearly horizontal and in position to be read. Another glass suspended half an inch above the ice gave the temperature of the air. Temperatures were taken every fifteen minutes, and humidity, weight and wind every hour.

These examples (Tables of January 11th, 12th and 21st on page 612) will suffice to show that ice over a body of water, as in a reservoir, has a more uniform temperature than ice experimented on in the open air. It will be found warmer on a cold day and cooler on a warm day than the ice in an evaporometer.

The best place to experiment on the laws governing the evaporation from ice is in a covered and cold shed, through and into which the wind cannot penetrate.

* Manchester Memoirs.

TEMPERATURES OF ICE.

JANUARY 11TH, 1886.					JANUARY 12TH, 1886.				
Time.	Temp. Ice on Res.	Temp. Air over Res.	Temp. Ice in Gauge in Yard.	Temp. Air over Ice in Gauge.	TIME.	Temp. Ice on Res.	Temp. Air over Res.	Temp. Ice in Gauge.	Temp. Air over Ice in Gauge.
Noon.	24.1	16.3	11.1	11.7	9 A.M.	9.7	—4.9	—6.9	—6.0
1 P.M.	24.1	16.3	13.3	13.8	10 "	15.4	—1.6	—5.6	—6.0
2 "	22.9	17.2	14.2	15.3	11 "	15.4	—1.6	—5.6	—2.7
3 "	22.3	16.0	13.3	13.8	12 M.	16.9	4.1	—4.2	—0.6
4 "	20.6	14.0	11 1	12.6	1 P.M.	17.8	5.5	—2.9	0.9
					2 "	15.4	6.1	—2.4	1.6

JANUARY 21ST, 1886.

Time.	No. 1.		No. 2.		No. 3.	
	Reservoir Surface.	Air.	Ice.	Air.	Ice.	Air.
			14 in. above Res.		Pan on Res.	
9 A.M.	32.4	31.1	29.7	30.4	30.6	30.4
10 "	32.4	33.8	32.0	34.3	32 0	33.8
11 "	32.7	34.3	32.5	35.4	32.5	35.6
12 M.	32.7	37.4	32.5	37.6	32.5	37.0
1 P.M.	32.7	40.1	32.5	38.8	32.5	37.9
2 "	32.5	38.7	32.5	38.7	32.5	37.9
3 "	32.5	37.9	32.9	38.5	32.5	37.9
4 "	32.4	34.7	32.5	37.2	32.5	34.7

FEBRUARY 17TH, 1886.

Time.	Ice.	Air.
9 A. M	21.4	19.8
10 "	22.3	23.0
11 "	25.2	25.7
12 M.	27.9	27.9
1 P. M	29.5	29.3
2 "	29.7	28.9
3 "	29.7	30.2
4 "	29.7	29.3
5 "	28.2	27.1

Here the temperature of the ice is more uniform, and follows pretty closely that of the air, as will be seen by the example (Tables of February 17th, 1886).

If the dew point be carefully determined by condensation, and the other observations are sufficiently accurate, it will be found that the rate of evaporation corresponds with that computed by means of the formula on page 589. The following experiment is selected as showing the different temperatures of an ice surface as determined by burying the bulb of a thermometer so that half its circumference was below the surface of the ice, as in column No. 1, and by simply allowing the thermometer to rest upon the ice, as in column No. 2.

February 24th, 1886.

Time.	Temp. of Ice. Bulb Half Buried.	Temp. of Ice. Bulb Exposed.	Dry Bulb.	Wet Bulb.	Dew Point by Condensation.	Evaporation.
8 A.M.....	23.4	21.9	16.0	15.0	10.6	
9 "	20.7	19.4	17.3	16.7	9.3	
10 "	20.3	19.8	18.0	17.0	12.2	
11 "	21.2	20.8	19.8	19.0	14.7	
12 M.	22.5	22.5	21.2	20.0	14.7	
1 P.M.....	23.9	23.5	22.0	20.8	15.1	
2 "	24.3	23.9	22.2	21.0	14.2	
3 "	24.4	24.3	23.0	21.0	14.7	
4 "	24.3	24.3	22.3	20.5	13.6	Total,
5 "	23.0	22.6	21.3	20.0	11.8	0.0038 inch.

The readings of the psychrometer and of a condensing hygrometer are both given in the above table, and the values of V and v may be selected according to the individual judgment, and according to the tables or formulas used for determining v and the dew point.

Taking the values of V from column No. 2, and the largest values of v which the notes give, the observed total evaporation in the nine hours, viz., 0.0038 inch, agrees almost perfectly with the amount, 0.0042 inch, computed by the formula, and taking any of the other values indicated above, does not lead to more serious differences than might be expected when the very small amounts of evaporation in this case are considered.

On the same day an experiment was made with an ice surface

exposed to a strong wind, with the following results: The mean force of vapor due to the temperature of the surface of the ice for 7 hours, 10 A.M. to 5 P.M., with the observations taken hourly, was 0.117 inch. The mean force of vapor in the air was 0.045 inch. The number of miles run by the wind (anemometer set at the same level with the ice) was 85.4, or 12.2 miles per hour. Here we have

$$\frac{(V-v)\left(1+\frac{w}{2}\right)}{60}=\frac{.072\times 7.1}{60}=0.00852 \text{ inch}$$

per hour, or .0596 inch, total computed evaporation. The observed evaporation was .0575 inch. The range of temperature of the ice surface was 6 degrees, viz.: from 17.9 to 23.9 degrees.

There are many days in winter when the surface of the ice is very wet, or covered with pools of water. In forming an estimate of the evaporation, this fact should not be lost sight of.

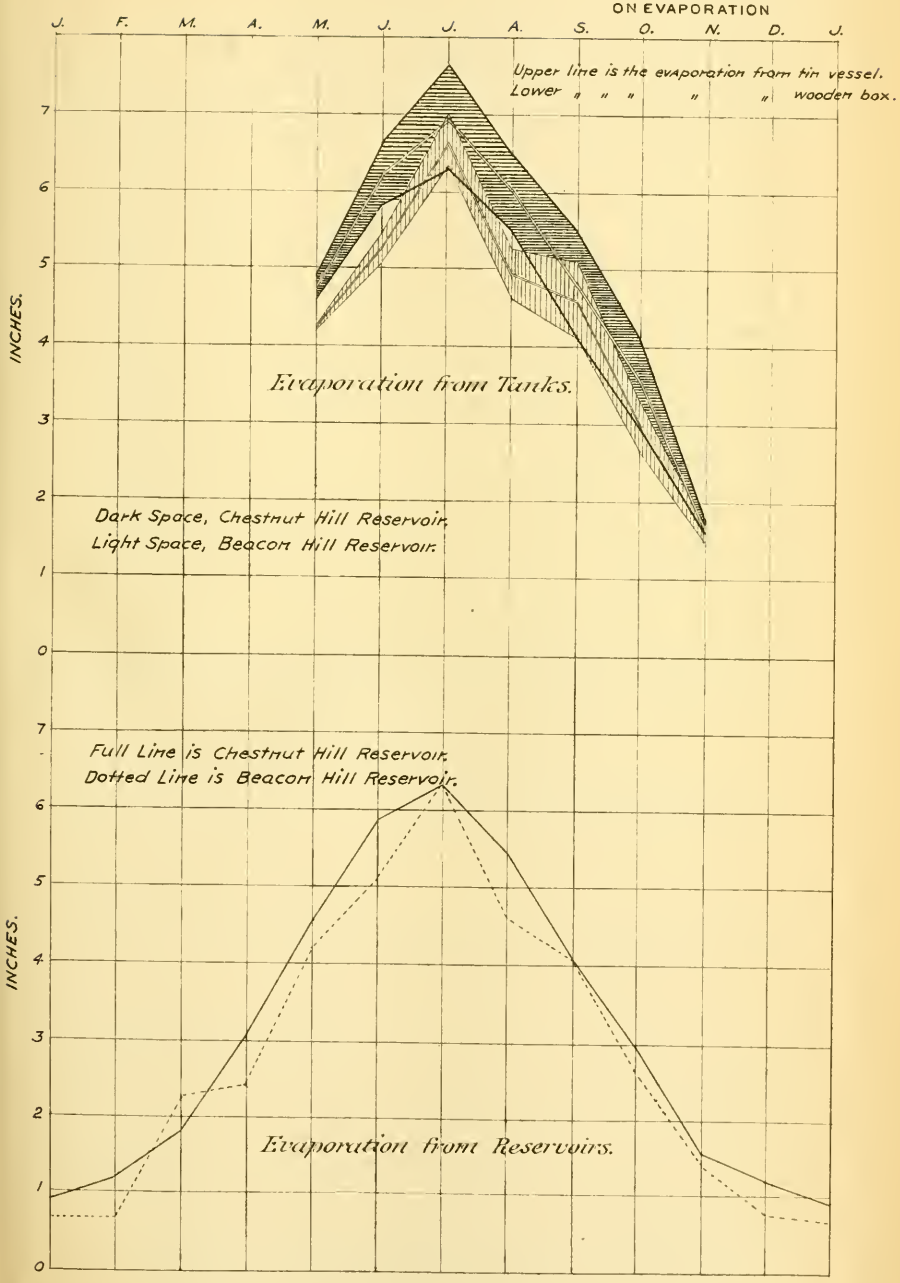
As already mentioned on page 601, the writer has known a reservoir to be losing vapor in the middle of December, at the rate of about a quarter of an inch per day, but this is most unusual. After much consideration and study of all the elements, the following figures have been adopted as an estimate of the mean evaporation from a large body of water during the winter and spring months:

December	1.20	inches.
January	0.90	"
February	1.20	"
March	1.80	"

In arriving at these values, the writer has been aided by plotting profiles of a number of experiments, and making allowances for what he believes to be the mean condition of the ice during the different months. Accuracy is not pretended for them, but in his judgment they are probably less than the true means, whatever these may be.

Plate LXXIX contains on its upper portion, profiles of the evaporation from box and pan at Chestnut Hill Reservoir, represented by the darker shaded space, and the same from the Beacon Hill Reservoir in a lighter tint, the upper line being the tin and the lower the box in each case, while the white space in the middle of each is the mean between the box and tin in both cases.

The lower portion of the same plate contains values for the reservoir evaporations. The Chestnut Hill profile is made up of the box evapora-


J. F. M. A. M. J. J. A. S. O. N. D. J.
Upper line is the evaporation from tin vessel.
Lower " " " " " wooden box.
INCHES.
7 6 5 4 3 2 1 0
Evaporation from Tanks.
Dark Space, Chestnut Hill Reservoir.
Light Space, Beacon Hill Reservoir.
Full Line is Chestnut Hill Reservoir.
Dotted Line is Beacon Hill Reservoir.
INCHES.
7 6 5 4 3 2 1 0
Evaporation from Reservoirs.

tions as recorded, and of the preceding values for the winter months, and completing the curve gives 3.10 inches for April.*

Finally, getting the months together, we have the following values:

January	0.90
February	1.20
March	1.80
April	3.10
May	4.61
June	5.86
July	6.28
August	5.49
September	4.09
October	2.95
November	1.63
December	1.20
Total	39.11

and we may find a mean curve by submitting these means to a mathematical computation, by the method of Bessel's Circular Function, which cannot fail to add very much to their value, in which, according to Sir John Herschel, the elements may be considered

First.—Independent of the others (or the mean).

Second.—The extent and law of its deviation from that amount.

Third.—Their mutual interdependence, or the reaction of each element on the rest.

The following is the formula:†

$E = A + B_1, \text{Sin}\,(\Theta + C_1), + B_2 \text{ Sin}\,(2\,\Theta + C_2) + B_3 \text{ Sin}\,(3\,\Theta + C_3),$

in which

E = evaporation in any one month in inches.

A = mean monthly amount.

$B_1\ B_2\ B_3$ = the parameter of its fluctuations for periods of 1, $\frac{1}{2}$ and $\frac{1}{3}$ year.

Θ = arc proportional to time, and inversely proportional to the period (360 degrees), or 30 degrees for one month.

* The writer once measured (1880) an evaporation of 1.31 inches in 8 days, in April.

† See Appendix No. 22 to the Report of the Superintendent of the Coast Survey for 1862; also Ency. Brit., 8th ed., article "Meteorology."

C_1 C_2 C_3 = angular constants having reference to the epochs of their respective periods.

MEAN CURVE OF EVAPORATION CORRECTED BY ABOVE FORMULA.*

	Inches.	Per Cent.
January	0.98	2.51
February	1.01	2.58
March	1.45	3.71
April	2.39	6.11
May	3.82	9.76
June	5.34	13.65
July	6.21	15.87
August	5.97	15.26
September	4.86	12.42
October	3.47	8.87
November	2.24	5.73
December	1.38	3.53
	39.12	100.00

The above values are plotted on Plate LXXX. They had already been secured before the writer thought of comparing them with the mean temperature; but the surprising correspondence of the two curves is very striking. The upper curve of dotted lines on the same diagram is the mean temperature for 15 years furnished by the United States Signal Office in Boston.

OTHER EXPERIMENTS.—AMERICAN.

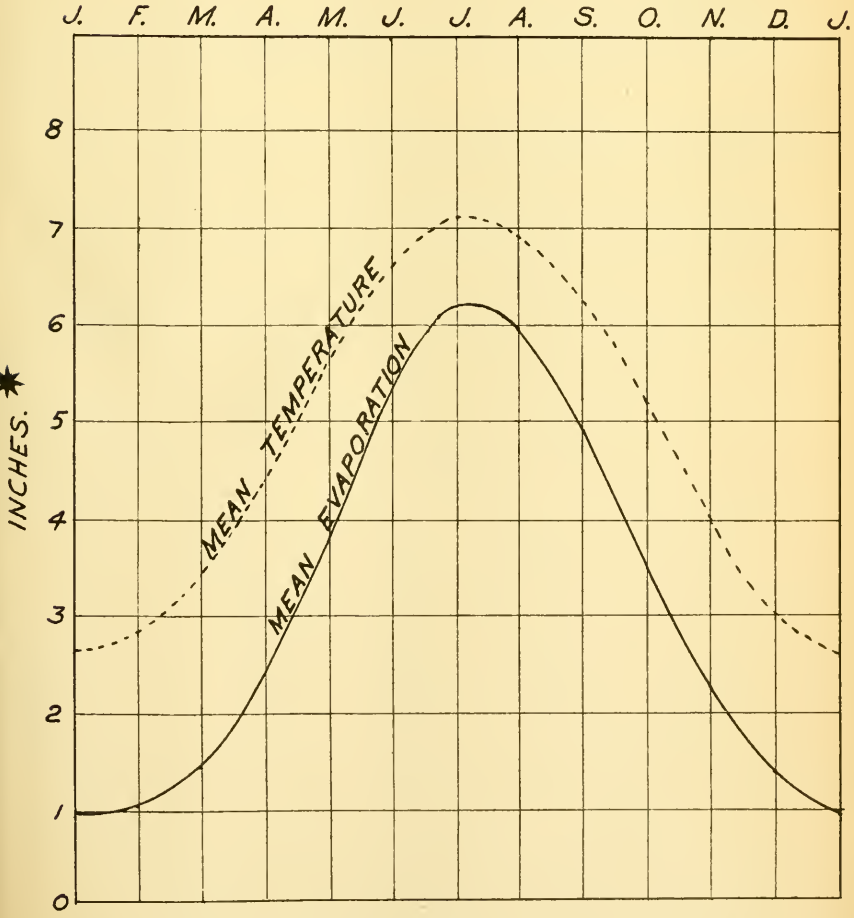
Evaporation experiments in this country are not numerous. Probably the earliest were made by Rev. Samuel Williams† in 1772, at Bradford, Mass.

Two vessels, 3 inches diameter and 6 inches deep, were used. It was found that by filling one of these vessels once a week and the other once a month, there was one-third more evaporation in the former case than in the latter. By floating one of his vessels in the Merrimac River during a week when there was little wind, still water and no rain, the result-

*The writer is aware that few engineers understand the value of the application of Bessel's circular function to a mass of observed periodic data, such as those under consideration. The labor of computation is considerable, but the results more than repay any time and trouble given to obtain them.

† Transactions Am. Phil. Soc., Vol. II, p. 119.

Mean Curve of Evaporation compared with Mean Temperature Curve.



✷ *For the Temperature Curve add a cipher and read degrees instead of inches.*

ing evaporation was as 1.15 inches to 1.50 inches in the freely exposed gauge.

Between 1865 and 1870, experiments were made on the Croton Waterworks, both at the receiving reservoir and at Boyd's Corner, the latter by Mr. J. J. R. Croes, M. Am. Soc. C. E., to whom the writer is indebted for the details of the experiments.

"The mean annual evaporation for six years was 39.21 inches, 81 per cent. of the rainfall. Observations were made on the West Branch from June, 1866, to October, 1870. The apparatus consisted of a box 4 feet square and 3 feet deep, sunk in the earth in an exposed situation, and filled with water. The mean annual evaporation was found to be 24.15 inches, while from a similar box at the receiving reservoir the amount observed was 35.6 inches.

"Part of the difference may be due to difference of latitude, elevation, and distance from the sea-coast; but more is due, I think, to differences in the mode of measurement. My observations were made twice a day, and any apparent discrepancies were checked and corrected at once, The other observations were taken only once a month, the difference between rainfall and the reading of the gauge on the box being taken as the evaporation. I consider the method followed on the West Branch the more reliable. The box was zinc-lined, and readings made with hook gauge."

The following table gives the yearly amounts secured at the receiving reservoir:

	Months.	Box in Earth.	Box in Reservoir.	Tin in Reservoir.
1865	10	35.24	36.05	39.19
1866	10	37.61	41.55	43.84
1867	9	31.08	33.98	34.75
1868	8	33.18	35.06	37.57
1869	8	29.85	34.57	39.93
Means	.....	33.39	36.12	39.05

One year, 1870, is missing, but as we have above the mean, 39.21, given, we can supply the loss. It would require 54.65 for the box, and 39.98 for the tin, so that the results of the tin were probably taken; but

as for two of these years the observations only include 8 months; for one year, 9 months; and for two others, 10 months, it is obvious that the amount of 39.21 is not large enough. The only alternative is to consider the evaporation for the winter months so trifling, that it may be left out of the estimate altogether, which cannot be done, unless the investigations already shown are a failure.

The tin vessel at Chestnut Hill Reservoir was found to give too large results. It would be better to take the floating box and supply the missing months from the Boston experiments. First, let us see if there is a correspondence in the other months. The following table will show:

	New York.	Boston.
April	2.53	2.39
May	4.16	3.82
June	4.98	5.34
July	6.43	6.21
August	6.74	5.97
September	5.02	4.86
October	3.03	3.47
November	2.48	2.24
Total	35.37	34.30

This is believed to be a fair correspondence. Supplying the missing months, we get 39.64 as the mean for the five available years, or about 82 per cent. of the rainfall.

We now come to Mr. Croes' observations on a wooden box, sunk in the earth at Boyd's Corner, from which he deduced the low evaporation of 24.15 inches. The observations extended from July 1, 1866, to October, 1870, about four years. Mr. Croes has been unable to find the observations made in 1870, so that we have three complete years only with monthly results. One covers 10 months; one, 9 months; and one, 8 months, so that the evaporation needs certainly to be increased somewhat for the missing months, and probably somewhat for the fact of the gauge being unsurrounded with water; for we find the gauge correspondingly situated at the receiving reservoir gave less than the floating box. Even with these corrections, Mr. Croes' results are very much less than the others. As the experiments were made with greater care than at the

receiving reservoir, there is little doubt but that they represent the actual evaporation from the box as situated; but in the writer's opinion they cannot be accepted as representing the evaporation from a large body of water. Perhaps the water was colder, the velocity of the wind less, or the surface of the water may have been kept a greater distance below the top of the box than in the other experiments.

The following example is here brought in somewhat out of place as possibly illustrating the above.

At the Glencore filters,* South Pentlands, the evaporation from the surface of the water in a tub was observed for upwards of twenty years. The tub was 6 feet diameter and 3 feet deep. The description does not say how far below the top of the tub the water was usually kept, but from the following extract, the writer infers that the level must have been altogether too low to give good results. "The level of the surface of the water, when set at 0, is 1 foot below the top, thus making the depth only 2 feet." The mean rainfall 1857–80 was 38.8 inches, and the evaporation 11.42 inches. The reader is asked to compare this result with Mr. Greaves' experiments, page 620.

To give an idea of how considerable the mean evaporation from a large body of water must actually be in December, the writer would here call attention to the fact that Chestnut Hill Reservoir does not generally freeze over until the last of the month. During the years 1877–79 it did not vary more than one day from Christmas. In 1880 it closed in on the last of November, but the following year it was open until the 14th of January, which was also the case this year, 1886.

The ice generally disappears about the middle of March or 1st of April, but during some of this time the surface is in a very watery condition.

English Experiments.

Those made by the late Mr. Charles Greaves, C. E.,† are probably the best that have been published. They were taken from a floating slate gauge 3 feet square, with water from 3 to 7 inches in depth. The following table shows the rainfall and evaporation for fourteen years:

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* Min. Inst. of Civil Engineers, Vol. LXXI, p. 74.

† Min. Proc. Inst. C. E., Vol. XLV, p. 19.

Year.	Evaporation.	Rainfall.
1860	21.058	32.558
1861	25.008	23.633
1862	17.332	26.581
1863	18.266	19.766
1864	18.640	15.891
1865	20.124	29.248
1866	18.821	31.697
1867	20.061	27.436
1868	26.933	23.308
1869	19.062	24.562
1870	20.396	20.395
1871	19.583	24.083
1872	22.916	37.166
1873	20.395	23.770
Mean	20.613	25.721

The relation of the evaporation to the rainfall, 82 per cent., was about the same as in the experiments recorded by the writer.

The following table has been compiled from Mr. Greaves' paper.

Month.	Evaporation.	Per Cent.
January	0.755	3.6
February	0.603	2.9
March	1.065	5.2
April	2.098	10.2
May	2.753	13.4
June	3.142	15.2
July	3.443	16.7
August	2.849	13.8
September	1.606	7.8
October	1.056	5.1
November	0.669	3.3
December	0.574	2.8
Total	20.613	100.0

In the discussion which followed Mr. Greaves' paper (February, 1876), some valuable facts were elicited. Mr. Rogers Field stated that "British Rainfall" for 1869 gave the results of evaporation from thirteen stations as varying from 10 to 48 inches. English engineers had generally adopted 30 inches as the yearly evaporation, French engineers 51 to 59 inches at Paris, but experiments on the Canal de Bourgogne

gave 22 to 25 inches, and numerous experiments in different parts of France with brick tanks, had given from 18 to 25 inches. The difference in gauges was the key to the discrepancies.

Mr. Miller* found the mean evaporation to be 30 inches for six years from a small vessel fully exposed above ground. His monthly results are interesting, not as representing the true evaporation from a large body of water, but as giving the relations between the different months. The per cent. column has therefore been added.

Month.	Evaporation.	Per Cent.
January	0.880	2.9
February	1.042	3.5
March	1.770	5.9
April	2.535	8.4
May	4.146	13.9
June	4.547	15.1
July	4.200	14.0
August	3.398	11.3
September	3.174	10.6
October	1.930	6.4
November	1.322	4.4
December	1.087	3.6
Total	30.032	100.0

Mr. G. Dines, who has experimented much on evaporation, found† the loss from a small gauge, 5 inches diameter, 2½ inches deep, all except the bottom exposed to the air, gave 76 per cent. more evaporation than a gauge 18 inches diameter.

Mr. Dines, Mr. Baldwin Latham and Mr. Rogers Field, among Englishmen, have all shown a lively interest in the subject of evaporation, and from their writings show that they understand the importance of the subject and the general principles upon which it depends. Mr. Latham has been experimenting on the subject for the Royal Society, but the results have not yet been published.

French Experiments.

Among the best that the writer has been able to find, are those of

* Practical Treatise on Heat, Thomas Box, p. 147.
† Symon's Meteorological Mag., Vol V, p. 71.

Mr. A. Salles, whose observations were made at Arles.* He used three tanks of masonry, each 3 meters square (9 feet 10 inches), and containing 96.8 square feet. The depth of water was kept at about 1.6 feet in No. 1, 3 feet in No. 2, and 4.8 feet in No. 3. Special instruments were designed for accurate measurements. The general results were as follows. The mean annual evaporation was 41.3 inches. A Piche atmismometer gave 86.6 inches (this is a small instrument). The monthly evaporation varied from a minimum of practically 0 to 7.8 inches maximum in July. The greatest daily evaporation observed occurred on July 31, 1878. It was 0.56 inch in No. 1, and 0.55 inch in No. 2.

The engineers of the "Ponts et Chaussées" have found,† from numerous experiments on brick tanks at St. Jean de Losne, Dijon, Pouilly, and at Roche sur Yonne, that the mean annual evaporation is about 23 inches, or 73 per cent. of the rainfall. Once only in 1842, at Pouilly, did the evaporation exceed the rainfall.

Russian Experiments.

An extensive series of comparative experiments has been conducted throughout the Russian Empire by H. Wild. The observations were taken at twenty-three different places, and covered periods from one to seven years, generally two years at each place. They are fully discussed in Mr. Ed. Stelling's able articles on the subject.‡ As the evaporations were all taken under shelter, and with a shallow weighing atmometer, known as "Wild's Wagevaporometer,"§ the results cannot give any idea of the real loss from a large body of water. They, however, form a basis for judging of the comparative evaporations at the different stations, as care was taken to have the conditions of exposure uniform. Two of Stelling's papers have been more fully noticed in the Theoretical discussion.

The writer has avoided dwelling at length in this paper on the many attempts to register evaporation by observations on small evaporating dishes freely exposed to the sun on the sides, and not immersed in water. Such attempts must inevitably result in failure to show, even approximately, the losses by evaporation from a large body of water.

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* Comptes Rendus, 1883, Vol. XCVII, p. 347.

† Annales des Ponts et Chaussées, 2d Series, Vol. XX, p. 383.

‡ K. Academie der Wissenschaften, St. Petersburg, Repertorium VII–VIII, 1880–81.

§ Bulletin de l'Academie Impériale des Sciences de St. Petersburg, Vol. XIX.

Hourly Observations July 8th.–11th. 1885.

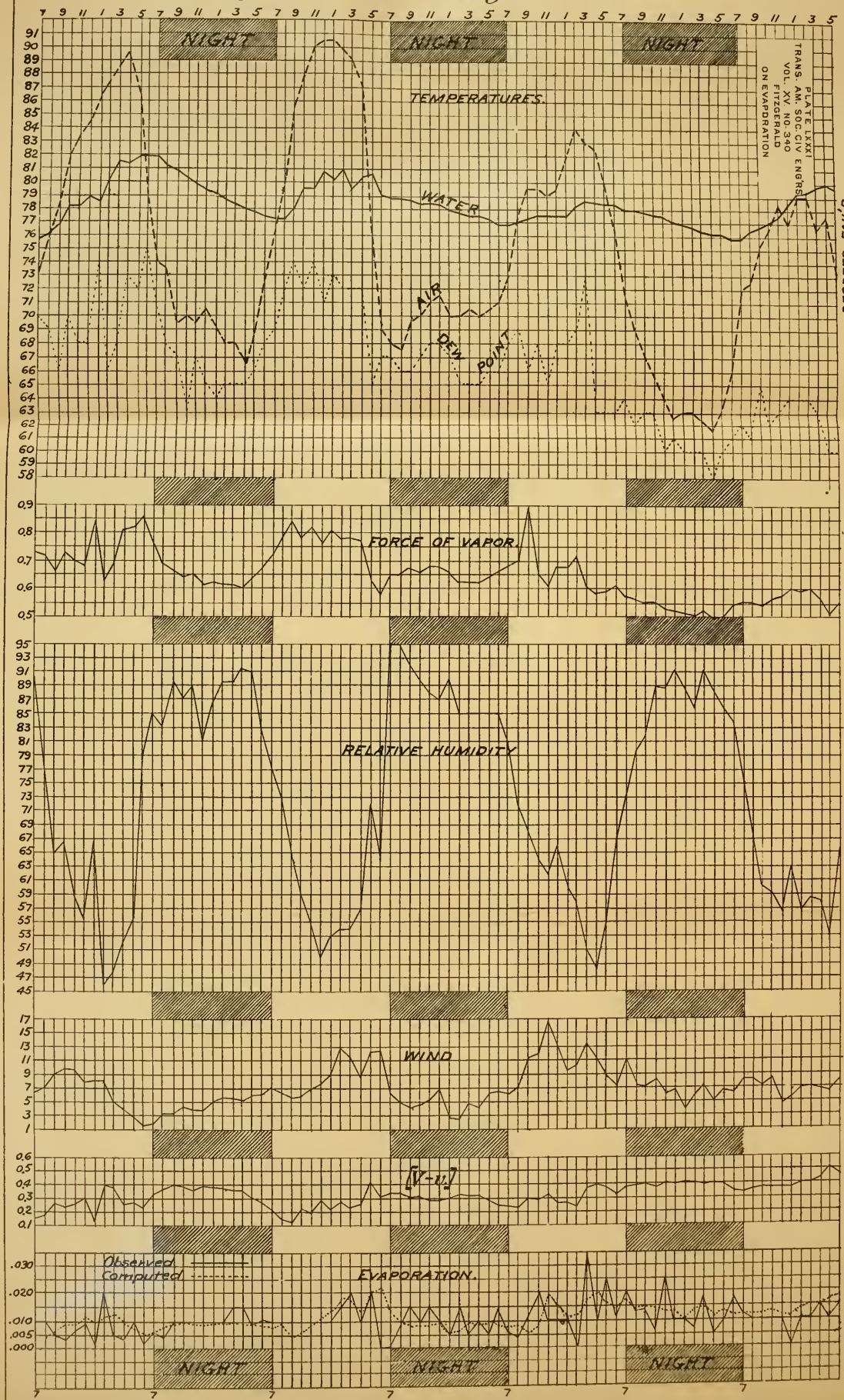

TABLE No. 1.

Comparison Between Registering Thermometers and Baudin Standard.

Reservoir.

Date.	Huddleston.			Baudin.			Green.		
	Max.	Min.	Mean.	Max.	Min.	Mean.	Max.	Min.	Mean.
1885.									
July 24.....	81.0	76.5	78.7	79.5	78.3	78.9	79.7	77.8	78.7
25.....	83.0	77.0	80.0	81.9	77.9	79.9	81.7	77.8	79.7
26.....	83.5	78.0	80.7	82.5	79.0	80.7	82.2	78.8	80.5
27.....	....	....	....	80.5	77.7	79.1	81.7	77.8	79.7
28.....	83.0	75.0	79.0	80.5	77.2	79.0	81.7	77.3	79.5
29.....	80.0	75.0	77.5	78.6	77.0	77.8	78.7	76.8	77.7
30.....	79.0	75.5	77.2	76.8	76.8	76.8	77.7	76.3	77.0
31.....	85.0	74.0	79.5	79.2	75.7	77.9	82.7	75.8	79.2
Aug. 1.....	81.0	76.0	78.5	77.9	76.8	77.3	80.2	76.3	78.2
2.....	79.0	75.0	77.0	76.8	76.2	76.5	77.7	74.8	76.2
3.....	77.0	74.0	75.5	76.0	74.9	75.4	76.2	74.8	75.5
4.....	78.0	74.0	76.0	77.0	74.1	75.5	76.7	73.8	75.2
Tank No. 1.									
5.....	84.5	71.0	77.7	82.2	73.4	77.8	82.7	72.5	77.6
6.....	82.0	72.0	77.0	76.6	73.8	75.2	80.7	73.5	77.1
7.....	79.0	70.0	74.5	77.5	73.2	75.3	78.2	72.5	75.3
8.....	77.5	72.0	74.7	76.9	73.6	75.2	76.7	73.5	75.1
9.....	77.0	71.0	74.0	76.5	73.6	75.0	76.7	73.5	75.1
10.....	79.0	71.0	75.0	77.0	73.6	75.3	77.2	73.5	75.3
11.....	79.0	72.5	75.7	78.0	73.8	75.9	79.7	74.0	76.8
12.....	83.5	72.5	78.0	82.2	74.8	78.5	82.7	74.5	78.6
13.....	82.0	76.0	79.0	79.6	76.4	78.0	80.7	76.5	78.6
14.....	84.0	76.5	80.2	81.4	76.4	78.9	81.7	76.5	79.1
15.....	80.5	73.0	76.7	77.6	75.2	76.4	79.7	75.0	77.3
16.....	79.0	72.0	75.5	77.0	73.4	75.2	78.7	73.5	76.1
17.....	78.0	70.0	74.0	76.6	72.8	74.7	77.7	71.5	74.6
18	80.0	72.0	76.0	77.8	73.0	75.4	78.7	73.0	75.8
19.....	78.0	73.0	75.5	76.6	73.8	75.2	76.7	73.5	75.1
20.....	74.5	72.0	73.2	74.8	72.8	73.8	75.7	72.5	74.1
21.....	76.5	70.0	73.2	74.2	72.4	73.3	77.7	71.5	74.6
22.....	78.5	73.0	75.7	78.9	72.4	75.6	78.7	71.5	75.1
23	78.5	72.0	75.2	77.0	72.4	74.7	78.7	71.5	75.1
24.....	78.0	73.0	75.5	78.8	72.6	75.7	78.7	71.5	75.1
25.....	77.0	70.0	73.5	....	....	....	77.7	71.5	74.6
26.....	71.0	68.5	69.7	70.8	69.6	70.2	77.7	69.6	73.6
27.....	71.0	65.0	68.0	68.8	67.0	67.9	70.7	63.5	67.1
28.....	73.5	64.0	68.7	71.6	66.8	69.2	71.7	64.5	68.1
29.....	73.5	65.0	69.2	70.4	67.2	68.8	71.7	65.5	68.6
30.....	71.0	65.0	68.0	69.0	67.6	68.3	70.7	66.5	68.6
31.....	74.0	66.0	70.0	72.0	66.6	69.3	73.2	65.5	69.3
Sep. 1.....	75.0	66.0	70.5	72.4	66.6	69.5	73.7	66.0	69.8
2.....	71.0	66.0	68.5	67.3	66.4	66.8	70.7	66.0	68.3
3.....	71.0	62.0	66.5	69.0	65.0	67.0	69.2	64.0	66.6
4.....	75.0	64.0	69.5	72.3	65.4	68.8	73.3	64.5	68.9
5.....	71.0	67.0	69.0	69.4	67.2	68.3	70.7	67.0	68.8
6.....	73.0	63.0	68.0	70.0	65.8	67.9	69.7	65 0	67.3
7.....	70.0	65.5	67.7	69.0	65.6	67.3	69.7	64.5	67.1
8.....	73.0	64.0	68.5	69.7	65.2	67.4	72.7	64.5	68.6
9.....	74.0	64.0	69.0	72.6	65.6	69.1	73.7	65.0	69.3
10.....	68.0	62.5	65.2	64.8	63.8	64.3	67.7	63.8	65.7
11.....	68.5	61.0	64.7	67.2	63.2	65.2	67.7	62.5	65.1
12.....	73.0	61.0	67.0	70.8	63.0	66.9	71.7	62.0	66.8
13.....	69.0	62.0	65.5	68.0	63.4	65.7	68.7	63.0	65.8
14.....	75.0	65.0	70.0	73.4	64.4	68.9	73.7	64.5	69.1
15.....	73.0	67.0	70.0	72.4	67.2	69.8	73.2	67.0	70.1
16.....	72.0	67.0	69 5	70.0	67.0	68.5	72.7	66.5	69.6
17.....	71.0	65.0	68.0	69.0	65.4	67.2	71.7	65.4	68.5
18.....	71.0	64.5	67.7	69.4	64.6	67.0	69.7	64.0	66.8

TABLE No. 1.—(*Continued.*)

Comparison of Maximum and Minimum Thermometers with Baudin Standard.

Tank No. 1.

Date.	Huddleston.			Baudin.			Green.		
	Max.	Min.	Mean.	Max.	Min.	Mean.	Max.	Min.	Mean.
1885.									
Sep. 19.....	69.5	65.0	67.2	67.3	65.4	66.3	68.7	64.5	66.6
20.....	68.0	63.0	65.5	66.5	64.8	65.6	66.7	63.5	65.1
21.....	68.5	61.0	64.7	67.0	65.0	66.0	66.7	62.5	64.6
22.....	66.5	62.0	64.2	65.6	64.6	65.1	65.7	62.5	64.1
23.....	....	....	....	....	....	....	....	....	....
24.....	66.0	57.0	61.5	59.8	59.0	59.4	....	....	....
25.....	67.0	57.5	62.2	61.8	59.4	60.6	66.7	58.0	62.3
26.....	67.0	56.5	61.7	66.0	59.2	62.6	66.2	58.0	62.1
27.....	70.0	58.5	64.2	68.0	60.4	64.2	69.7	69.0	64.3
28.....	67.5	61.0	64.2	66.6	62.0	64.3	66.7	61.5	64.1
29.....	67.0	61.0	64.0	65.4	62.4	63.9	66.7	61.5	64.1
30.....	66.5	60.5	63.5	65.2	62.0	63.6	65.7	61.0	63.3
Oct. 1.....	66.0	59.0	62.5	65.2	61.8	63.5	65.7	60.5	63.1
2.....	64.0	60.0	62.0	62.8	61.8	62.3	63.7	61.0	62.3
3.....	63.5	61.0	62.2	61.7	61.2	61.4	62.7	59.5	61.1
4.....	67.0	63.0	65.0	66.0	63.4	64.7	66.7	62.0	64.3
5.....	65.5	59.0	62.2	61.0	60.6	60.8	65.7	59.5	62.6
6.....	....	....	....	....	59.0	....	....	....	....
7.....	....	....	....	56.8	56.8	56.8	....	....	....
8.....	57.0	53.0	55.0	56.0	55.8	55.9	57.7	54.0	55.8
9.....	57.0	53.0	55.0	56.2	55.0	55.6	56.2	53.5	54.8
10.....	59.0	52.0	55.5	58.2	54.4	56.3	58.2	53.0	55.6
11.....	60.0	53.0	56.5	59.0	55.0	57.0	63.7	54.5	59.1
12.....	57.0	51.0	54.0	56.2	54.8	55.5	57.2	53.0	55.1
13.....	56.0	53.0	54.5	55.0	54.0	54.5	55.7	53.0	54.3
14.....	59.0	54.0	56.5	58.0	54.0	56.0	58.2	53.0	55.6
15.....	59.0	53.0	56.0	56.8	54.1	55.4	57.7	53.5	55.6
16.....	62.0	52.0	57.0	59.8	54.2	57.0	60.7	52.5	56.6
17.....	60.0	52.0	56.0	59.6	54.2	56.9	61.7	53.5	57.6
18.....	62.0	54.0	58.0	61.0	54.6	57.8	61.7	54.5	58.1
19.....	62.5	55.5	59.0	60.3	55.4	57.9	62.7	54.5	58.6
20.....	62.0	55.0	58.5	60.5	55.8	58.1	60.7	55.5	58.1
21.....	60.5	57.5	59.0	59.2	57.8	58.5	60.7	57.0	58.8
22.....	60.0	54.0	57.0	56.2	55.4	56.3	58.7	55.0	56.8
23.....	59.0	52.0	55.5	57.0	54.4	55.7	57.7	53.0	55.3
24.....	57.0	51.0	54.0	56.1	53.8	54.9	56.7	53.0	54.8
25.....	57.0	51.0	54.0	56.0	53.6	54.8	56.7	52.0	54.3
26.....	59.0	50.5	54.7	58.8	53.2	56.0	60.7	52.0	56.3
27.....	60.0	51.0	55.5	58.2	53.2	55.7	58.7	52.0	55.3
28.....	57.0	52.0	54.5	55.0	53.6	54.3	56.7	53.0	54.8
29.....	56.0	53.0	54.5	54.5	53.8	54.1	55.2	53.5	54.3
30.....	55.0	52.0	53.5	54.6	52.0	53.3	55.2	52.5	53.8
31.....	53.0	47.5	50.2	51.4	51.4	51.4	51.4	50.0	50.7

TABLE No. 1.—(*Continued.*)

Comparison of Mean Temperatures.

RESERVOIR.				TANK No. 1.				TANK No. 1.				TANK No. 1.			
Date.	Huddleston Registering.	Baudin.	Green Registering.	Date.	Huddleston Registering.	Baudin.	Green Registering.	Date.	Huddleston Registering.	Baudin.	Green Registering.	Date.	Huddleston Registering.	Baudin.	Green Registering.
1885.	Mean.	Mean.	Mean.	1885.	Mean.	Mean.	Mean.	1885.	Mean.	Mean.	Mean.	1885.	Mean.	Mean.	Mean.
July 24....	78.7	78.9	78.7	Aug. 5....	77.7	77.8	77.6	Sept. 1....	70.5	69.5	69.8	Oct. 1...	62.5	63.5	63.1
25....	80.0	79.9	79.7	6....	77.0	75.2	77.1	2....	68.5	66.8	68.3	2....	62.0	62.3	62.3
26....	80.7	80.7	80.5	7....	74.5	75 3	75.3	3....	66.5	67.0	66.6	3....	62.2	61.4	61.1
27....	....	79.1	79.7	8....	74.7	75.4	75.1	4....	69.5	68.8	68.9	4....	65.0	64.4	64.3
28....	79.0	79.0	79.5	9....	74.0	75.0	75.1	5....	69.0	68.3	68.8	5....	62.2	60.8	62.6
29....	77.5	77.8	77.7	10 ...	75.0	75.3	75.3	6....	68.0	67.9	67.3	6....	....	....	....
30....	77.2	76.8	77.0	11....	75.7	75.9	76.8	7....	67.7	67.3	67.1	7....	....	56.8	....
31....	79.5	77.9	79.2	12....	78.0	78.5	78.6	8....	68.5	67.4	68.6	8....	55.0	55.9	55.8
Aug. 1....	78.5	77.3	78.2	13...	79.0	78.0	78.6	9....	69.0	69.1	69.3	9....	55.0	55.6	54.8
2....	77.0	76.5	76.2	14....	80.2	78.9	79.1	10...	65.2	61.3	65.7	10....	55.5	56.3	55.6
3....	75.5	75.4	75.5	15....	76.7	76.4	77.3	11....	64.7	65.2	65.1	11....	56.5	57.0	59.1
4....	76.0	75.5	75.2	16....	75.5	75.2	76.1	12....	67.0	66.9	66.8	12....	54 0	55.5	55.1
				17....	74.0	74.7	74.6	13....	65.5	65.7	65.8	13....	54.5	54.5	54.3
Mean.....	78.1	77.9	78.1	18....	76.0	75.4	75.8	14....	70.0	68.9	69.1	14....	56.5	56.0	55.6
				19....	75.5	75.2	75.1	15....	70.0	69.8	70.1	15 ..	56.0	56.0	55.6
				20....	73.2	73.8	74.1	16....	69.5	68.5	69.6	16....	57.0	57.6	56.6
				21....	73.2	73.3	74.6	17....	68.0	67.2	68.5	17....	56.0	57.5	57.6
				22....	75.7	75.6	75.1	18....	67.7	67.0	66.8	18....	58.0	57.8	58.1
				23....	75.2	74.7	75.1	19....	67.2	66.3	66.6	19....	59.0	57 9	58.6
				24....	75.5	75.7	75.1	20....	65.5	65.6	65.1	20....	58.5	58.1	58.1
				25....	73.5	....	74.6	21....	64.7	66.0	64.6	21....	59.0	58.5	58.8
				26....	69.7	70.2	73.6	22....	64.2	65.1	64.1	22....	57.0	56.3	56.8
				27....	68.0	67.9	67.1	23....	....	....	....	23....	55.5	55.7	55.3
				28....	68.7	69.2	68.1	24....	61.5	59.4	....	24....	54.0	54.9	54.8
				29....	69.2	68.8	68.6	25....	62.2	60.6	62.3	25....	54.0	54.4	54.3
				30....	68.0	68.3	68.6	26....	61.7	62.6	62.1	26....	54.7	56.0	56.3
				31....	70.0	69.3	69.3	27....	64.2	64.2	64.3	27....	55.5	55.7	55.3
								28....	64.2	64.3	64.1	28....	54 5	54.3	54.8
				Mean.....	74.2	74.2	74.5	29....	64.0	63.9	64.1	29....	54.5	54.1	54.3
								30....	63.5	63.6	63.3	30....	53.5	53.3	53.8
												31....	50.2	51.4	50.7
								Mean.....	65.5	66.1	66.5				
												Mean.....	56.8	56.9	56.9

TABLE No. 2.

Mean Temperature and Evaporation from Tanks.

Date.	Res.	Tank No. 1.		Tank No. 3.
	Mean Temp.	Mean Temp.	Evap.	Evap.
1885				
May 11....	52.2	57.1	....	....
12....	52.7	56.1	....	0.16
13....	53.2	55.6	....	0.18
14....	52.7	44.6	....	0.05
15....	53.7	58.6	....	0.12
16....	54.7	59.6	0.18	0.10
17....	56.7	59.1	0.17	0.18
18....	57.2	58.6	0.06	0.04
19....	60.2	64.1	0.13	0.10
20....	59.6	61.3	0.19	0.16
21....	60.7	62.8	0.18	0.19
22....	61.9	64.1	0.16	0.16
23....	62.4	63.6	0.09	0.09
24...	61.7	64.3	0.15	0.11
25....	63.7	60.1	0.06	0.07
26....	64.9	67.1	0.14	0.18
27....	65.7	67.3	0.16	0.25
28....	65.7	65.1	0.20	0.29
29....	66.2	....	0.17	0.24
30....	65.4	....	....	0.24
31....	64.7	....	....	0.11
Total.....	1255.9	1099.1	2.04	3.02
Mean.....	59.8	61.1	0.16	0.15
	21 days	18 days	14 days	20 days

May.		Mean Temp.	Total Evap.
16th–29th, 13 days.	Reservoir.....	61.2	....
	Tank No. 1.....	62.8	1.87
	" No. 3.....	....	1.92

Date.	Res.	Tank No. 1.		Tank No. 3.		Tank No. 2.	
	Mean Temp.	Mean Temp.	Evap.	Mean Temp.	Evap.	Mean Temp.	Evap.
1885.							
June 1.....	65.7	....	0.11	....	0.11	....	....
2.....	64.2	65.1	0.25	....	0.29	....	....
3.....	64.2	66.1	0.20	....	0.16	....	....
4.....	64.0	65.1	0.16	....	0.19	....	....
5.....	62.7	63.8	0.07	....	0.07	....	....
6.....	62.7	63.1	0.22	....	0.22	....	....
7.....	63.0	64.1	0.17	....	0.24	....	....
8.....	66.3	67.6	0.10	66.9	0.10	....	....
9.....	66.0	66.3	0.39	65.8	0.40	....	....
10.....	64.0	65.4	0.27	64.1	0.28	....	....
11.....	66.1	69.0	0.24	66.6	0.25	....	....
12.....	66.6	68.8	0.25	66.9	0.26	....	....
13.....	67.2	69.4	0.20	67.9	0.27	67.8	0.23
14.....	69.5	70.9	0.16	69.1	0.21	69.2	0.16
15.....	71.6	72.7	0.25	71.4	0.27	72.1	0.27
16.....	73.9	77.3	0.20	74.0	0.20	73.8	0.20
17.....	73.2	73.3	0.16	73.3	0.24	73 5	0.21
18.....	73.7	73.7	0.23	73.3	0.32	73.5	0.30
19.....	75.3	75.1	0.30	75.4	0.35	75.0	0.34
20.....	74.7	75.4	0.20	75.4	0.37	75.1	0.34
21.....	73.4	73.5	0.27	73.2	0.34	73.5	0.32
22.....	73.5	73.4	0.31	73.0	0.25	73.8	0.27
23.....	70.7	69.8	0.57	69.9	0.58	70.8	0.64
24.....	69.8	69.5	0.44	69.4	0.49	70.1	0.50
25.....	70.6	71.4	0.27	70.4	0.32	71.0	0.32
26.....	72.2	74.9	0.20	73.0	0.25	73.7	0.24
27.....	73.1	74.8	0.20	74.1	0.22	74.6	0.23
28.....	74.1	74.4	0.15	74.1	0.16	74.2	0.16
29.....	75.4	77.2	0.10	76.2	0.12	76.8	0.08
30.....	72.9	72.3	0·31	72.5	0.33	73.3	0.32
Total.....	....	....	7.01	....	7.86	...	5.13
Mean... ...	69.3	70.4	0.23	71.1	0.26	72.9	0.28
	30 days	29 days	30 days	23 days	30 days	18 days	18 days

June.		Mean Temp.	Total Evap.
30 days	Res ..	69.3	....
	No. 1.	....	7.01
	No. 3.	....	7.86
29 days	Res...	69.5	....
	No. 1.	70.4	6.90
	No. 3.	....	7.75
23 days	Res ..	71.1	....
	No. 1.	72.0	5.83
	No. 3.	71.1	6.58
18 days	Res...	72.5	....
	No. 1.	73 3	4.58
	No. 3.	72.5	5.29
	No. 2.	72.9	5.13

TABLE No. 2.—(*Continued.*)

MEAN TEMPERATURE AND EVAPORATION FROM TANKS.

Date.	Res.	Tank No. 1.		Tank No. 2.		Tank No. 3.		Tank No. 5.		Tank No. 6.	
	Mean Temp.	Mean Temp.	Evap.	Mean Temp.	Evap.	Mean Temp.	Evap.	Mean Temp.	Evap.	Mean Temp.	Evap.
1885.											
July 1	71.0	69.4	0.33	71.0	0.34	70.4	0.33	....	....	....	....
2	71.0	70.8	0.27	71.4	0.34	70.9	0.33	....	....	...	....
3	71.8	71.5	0.20	72.0	0.25	71.6	0.26	....	....	....	....
4	74.4	75.1	0.13	75.6	0.14	74.3	0.16	....	....	....	....
5	74.5	75.4	0.17	75.4	0.19	74.6	0.20	....	....	....	....
6	74.4	74.3	0.18	74.9	0.20	74.7	0.19	....	....	....	....
7	75.3	75.7	0.13	76.0	0.27	75.3	0.27	75.5	0.31	75.3	0.26
8	78.7	78.8	0.12	79.4	0.11	78.4	0.13	79.1	0.14	79.0	0.16
9	79.1	79.9	0.22	80.2	0.27	79.4	0.13	79.2	0.31	79.2	0.20
10	77.7	77.8	0.29	78.3	0.23	77.7	0.30	77.7	0.21	77.6	0.30
11	77.8	77.7	0.29	78.3	0.30	77.5	0.29	77.1	0.30	77.3	0.28
12	77.1	76.8	0.31	77.5	0.39	76.4	0.38	76.5	0.38	76.4	0.34
13	76.8	76.2	0.24	76.8	0.30	76.4	0.27	75.8	0.27	75.8	0.25
14	74.5	74.2	0.29	74.5	0.25	74.3	0.23	73.6	0.22	73.5	0 20
15	75.3	75.9	0.19	75.6	0.23	74.9	0.25	74.9	0.27	74.9	0.25
16	78.1	77.8	0.21	78.0	0.26	78.0	0.24	78.1	0.24	78.0	0.24
17	78.4	79.7	0.17	79.3	0.19	78.7	0.19	78.9	0.22	78.9	0.20
18	80.3	80.2	0.20	80.5	0.24	80.0	0.26	80.3	0.26	80.2	0.25
19	78.7	79.4	0.33	79.0	0.37	79.3	0.37	78.2	0.35	78.2	0.33
20	80.4	80.1	0.25	80.6	0 28	80.4	0.29	80.1	0.30	80.1	0.29
21	79.3	79.3	0.36	79.4	0.31	79.5	0.32	79.7	0.30	79.6	0.32
22	80.6	80.1	0.22	80.1	0.29	79.7	0.30	79.5	0.28	79.6	0.29
23	80.1	80.1	0.28	80.8	0.34	80.0	0.34	79.8	0.33	79.8	0.32
24	78.9	79.0	0.28	79.2	0.30	78.8	0.31	78.4	0.27	78.5	0.29
25	80.0	80.9	0.14	81.2	0.17	80.0	0.17	80.2	0.17	80.2	0.16
26	80.7	80.7	0.24	80.3	0.20	80.7	0.21	80.3	0.21	80.3	0.21
27	79.1	79.3	0.33	80.1	0.44	78.8	0.43	77.5	0.38	77.8	0.39
28	79.0	78.2	0.28	78.4	0.34	78.3	0.34	78.5	0.36	78.1	0.33
29	77.8	76.0	0.20	77.6	0.24	77.5	0.24	77.3	0.21	77.3	0.23
30	76.8	76.2	0.17	76.7	0.10	76.5	0.09	75.8	0.10	75.8	0.11
31	77.9	77.6	0.12	79.6	0.16	79.0	0.17	78.9	0.15	78.9	0.15
Total	....	....	7.14	....	8·04	....	7.99	....	6.54	....	6.35
Mean	77.3	77.2	0.23	77.7	0.26	77.2	0.26	78.0	0.26	78.0	0.25
								25 days.	25 days.	25 days.	25 days

July.		Mean Temp.	Total Evap.
31 days	Res.	77.3	....
	No. 1	77.2	7.14
	No. 2	77.7	8.04
	No. 3	77.2	7.99
25 days	Res.	78.3	....
	No. 1	78.3	5 86
	No 2	78.7	6.58
	No. 3	78.2	6.52
	No. 5	78.0	6.54
	No. 6	78.0	6.35

TABLE No. 2 (*Continued*).

MEAN TEMPERATURE AND EVAPORATION FROM TANKS.

Date.	Res.	Tank No. 1.		Tank No. 2.		Tank No. 3.		Tank No. 4.		Tank No. 5.		Tank No. 7.	
		Mean Temp.	Evap.	Mean Temp.	Evap.	Mean Temp.	Evap.	Mean Temp.	Evap.	Mean Temp.	Evap.	Mean Temp.	Evap.
1885.													
Aug. 1	77.3	77.0	0.07*	78.5	0.09*	77.9	0.09	77.3	0.09	78.3	0.09	....	....
2	76.5	75.9	0.07*	76 8	0.09	76.5	0.09	76.3	0.09	76.5	0.09	....	....
3	75.4	74.9	0.28*	75.5	0.17	75.1	0.17	75.0	0.22	74.4	0.19	....	....
4	75.5	76.0	0.07*	76.1	0.09	75.7	0.16	75.8	0.25	75.0	0.14	....	....
5	77.9	77.8	0.31	79.2	0.25	77.9	0.26	78.4	0.26	78.2	0.26	....	....
6	76.0	75.2	0.34	76.5	0.32	75.8	0.32	76.0	0.29	75.0	0.31	....	....
7	75.2	75.3	0.31	75.9	0.28	75.3	0.27	75.3	0.25	74.7	0.27	75.2	0.27
8	75.0	75.4	0 27	75.6	0.26	75.0	0.26	74.9	0.26	74.6	0.26	74.5	0.25
9	74.8	75.0	0.22	75.1	0.23	75.1	0.23	75.0	0.22	74.0	0.23	75.0	0.22
10	75.0	75.3	0.20	76.0	0.18	75.2	0.20	75.4	0.18	75.2	0.20	75.9	0.28
11	75.6	75.9	0.23	76.1	0·16	75.5	0.18	75.4	0.14	75.3	0.16	76.0	0.16
12	76.8	78.5	0.20	78.2	0.14	77.4	0.14	77.6	0.15	77.9	0.10	79.0	0.14
13	77.5	78.0	0.17	77.4	0.14	77.3	0.13	77.5	0.13	77.5	0.14	78.4	0.15
14	78.1	78 9	0.25	78.7	0.20	78.0	0.21	78.1	0.21	78.2	0.23	79.1	0.20
15	76.3	76.4	0.37	76.7	0.38	75.8	0.33	75.0	0.33	75.1	0.35	75.1	0.29
16	75.5	75.2	0.30	75.8	0.32	75.1	0.32	75.1	0.30	74.1	0.32	74.2	0.24
17	75.0	74.7	0.31	75.7	0.36	75.1	0.32	75 0	0.33	74.6	0.34	74.9	0.29
18	75.0	75.4	0.28	75.7	0.26	74.8	0.26	74.9	0.27	74 8	0.26	75.4	0.26
19	74.9	75.2	0.24	75.6	0.20	75.0	0.19	75.1	0.20	74.7	0.20	75.3	0.20
20	74.5	73.8	0.36	74.8	0.34	74.1	0.33	74.0	0.31	73.4	0.34	73.5	0.28
21	73.5	73.3	0.23	73.9	0.24	73.4	0.22	73.3	0.22	72.7	0.22	72.8	0.20
22	74.9	75.6	0.19	76.5	0.22	75.5	0.22	75.5	0.22	75.7	0.22	76.4	0.22
23	73.9	74.7	0.29	74.5	0.24	74.0	0.24	73 9	0.22	73.7	0.20	74.1	0.19
24	74.4	75.7	0.11	76.0	0.10	75.2	0.11	75.8	0.15	75.5	0.14	76.7	0.13
25	73.7	74.4	0.05	73.0	0.05	72.7	0.05	72.9	0.05	72.5	0.05	73.0	0.05
26	71.9	70.2	0.48	71.6	0.50	71.1	0.45	70.9	0.36	70.5	0.45	69.3	0.40
27	70.0	67.9	0.48*	70.4	0.50	69.6	0.45	68.4	0.42	67.9	0.45	67.4	0.39
28	70.0	69.2	0.28	70.7	0.27	69 8	0.27	69.7	0.28	69.1	0.28	68.3	0.23
29	70.0	68.8	0.24	69.8	0.28	69.2	0.28	69.2	0.25	68.6	0.28	69.0	0.24
30	68.3	68.3	0.12	68.9	0.11	68.4	0.12	68.5	0.09	68.2	0.10	68.5	0.09
31	69.4	69.3	0.09*	70.8	0.08	69.7	0.06	69.8	0.04	69.5	0.06	70.5	0.06
Total ..	....	....	7.41	....	7.05	....	6.93	....	6.78	....	6.93	....	5.43
Mean ..	74 4	74.4	0.24	75.0	0.23	74.4	0.22	74.4	0.22	74.0	0.22	73.9 25 days.	0.22 25 days.

August		Mean Temp.	Total Evap.
31 days.	Res.	74.4	.....
	No. 1..	74.4	7.41
	No. 2 .	75.0	7.05
	No. 3..	74.4	6.93
	No. 4..	74.4	6.78
	No. 5..	74.0	6.93
25 days.	Res.	74.0	.....
	No. 1..	74.0	6.27
	No. 2..	74.5	6.04
	No. 3..	73.9	5.84
	No. 4..	73.8	5.58
	No. 5..	73.5	5.85
	No. 7..	73.9	5.43

* Assumed from data.

TABLE No. 2—(*Continued*).

Mean Temperature and Evaporation from Tanks.

Date.	Temp Res.	Tank No. 1.		Tank No. 2.		Tank No. 3.		Tank No. 4.		Tank No. 5.		Tank No. 7.	
		Mean Temp.	Evap.	Mean Temp.	Evap.	Mean Temp.	Evap.	Mean Temp.	Evap.	Mean Temp.	Evap.	Mean Temp.	Evap.
1885.													
Sep. 1	69.4	69.5	.17	70.3	.18	69.6	.18	69.6	.18	69.2	.18	70.0	.17
2	67.6	66 8	.39	68.0	.38	67.3	.35	67.2	.36	66.4	.35	66.2	.35
3	67 2	67.0	.23	67.9	.28	67.0	.27	67.0	.28	66.4	.26	66.7	.24
4	67.7	68.8	.15	69.1	.17	68.1	.16	68.2	.15	68.0	.15	69.0	.14
5	68.6	68.3	.07	69.1	.04	68.7	.04	68.6	.04	68.5	.04	69.1	.07
6	68.2	67.9	.19	68.5	.23	67.7	.21	67.9	.22	65.8	.20	66.0	.18
7	67.3	67.3	.17	67.6	.21	67.0	.21	67.0	.19	66.4	.20	66.3	.18
8	67.0	67.4	.17	67.7	.19	66.9	.17	67.1	.18	66.2	.17	66.9	.16
9	67.6	69.1	.11	69.1	.10	68.0	.11	68.3	.04	67.7	.10	69.0	.10
10	66.8	64.3	.27	66.0	.24	65.2	.26	65.0	.29	63.2	.24	63.6	.19
11	65 6	65.2	.17	66.2	.22	65.4	.22	65.7	.22	64.0	.21	65.0	.18
12	67.5	66 9	.16	68.3	.21	67.2	.20	67.6	.20	66.5	.13	67.4	.17
13	66.1	65.7	.14	66.9	.19	66.2	.19	66.5	.18	66.0	.17	67.2	.18
14	66.3	68.9	.10	68.2	.09	66.9	.09	68.1	.11	67.3	.12	69.2	.10
15	68.2	69.8	.09	68.7	.08	67.9	.08	68.5	.09	67.8	.09	69.1	.11
16	68.0	68.5	.18	68.1	.21	66.6	.21	67.9	.21	66.0	.20	66.3	.20
17	67.5	67.2	.24	68.6	.27	67.4	.24	67.7	.26	66.4	.24	66.6	.21
18	66.7	67.0	.20	67.0	.23	66.3	.22	66.7	.20	65.5	.21	66.3	.20
19	67.6	66.3	.19	66.8	.22	66.2	.21	66.3	.21	65.7	.22	65.4	.20
20	67.1	65.6	.20	67.6	.25	66.4	.24	66.6	.24	64.1	.22	65.3	.19
21	66.2	66.0	.15	66.4	.22	65.6	.22	66.0	.22	64.4	.20	64.4	.15
22	65.3	65.1	.13	65.5	.17	64.9	.16	65.0	.16	63.7	.15	64.0	.14
23	62.3	62.0	.31	62.5	.58	61.8	.55	62.0	.56	60.7	.50	61.2	.50
24	60.0	59.4	.30	60.3		59.6		59.5		58.2		58.7	
25	62.1	60.6	.14	62.3	.22	61.6	.21	61.8	.20	60.5	.14	62.0	.17
26	62.1	62.6	.13	63.0	.16	62.1	.17	62.7	.16	61.2	.14	62.2	.15
27	63.2	64.2	.06	64.9	.11	63.3	.11	63.9	.11	63.1	.11	64.8	.09
28	63.9	64.3	.07	64.9	.07	64.0	.07	64.5	.10	63.5	.08	64.7	.08
29	63.8	63.9	.10	63.9	.13	63.4	.12	63.7	.10	62.5	.11	63.1	.11
30	63.8	63.6	.12	64.0	.16	63.6	.17	63.8	.16	63.0	.17	63.1	.15
Total...	....	....	5.13	....	5.81	....	5.64	....	5.62	....	5.30	....	5.06
Mean ..	66.0	66.0	0.17	66.6	0.19	65.7	0.19	66.0	0.19	64.9	0.18	65.6	0.17

September.		Mean Temp.	Total Evap.
30 days	Res. ..	66.0	....
	No. 1..	66.0	5.13
	No. 2..	66.6	5.81
	No. 3..	65.7	5.64
	No. 4..	66.0	5.62
	No. 5..	64.9	5.30
	No. 7..	65.6	5.06

TABLE No. 2—(*Continued*).

MEAN TEMPERATURE AND EVAPORATION FROM TANKS.

Date.	Res. Mean Temp.	Tank No. 1.		Tank No. 2.		Tank No. 3.		Tank No. 4.		Tank No. 5.		Tank No. 7.	
		Mean Temp.	Evap.	Mean Temp.	Evap.	Mean Temp.	Evap.	Mean Temp.	Evap.	Mean Temp.	Evap.	Mean Temp.	Evap.
1885.													
Oct. 1	63.3	63.5	.14	63.7	.17	63.0	.16	63.4	.16	62.6	.15	62.7	.16
2	62.7	62.3	.08	62.8	*	62.2	*	62.3	*	60.9	*	61.2	*
3	61.7	61.4	.00	61.9	.00	62.0	.00	62.2	.00	61.8	.00	61.3	.00
4	63.3	64.4	.10	63.8	*	63.4	*	63.6	*	63.1	*	63.8	*
5	61.9	60.8	.25	61.6	.26	61.3	.26	61.3	.25	59.4	.15	59.4	.20
6	59.8	58.0	.11	59.8	.38	58.8	.36	59.0	.41	57.0	.35	55.5	.35
7	59.2	56.8	.24	59.2		58.7		58.8		55.9		55.0	
8	57.7	55.9	.14	58.4	.19	57.6	.20	57.8	.19	55.6	.19	55.4	.17
9	57.9	55.6	.17	57.9	.23	57.3	.23	57.4	.22	55.3	.21	55.4	.18
10	57.5	56.3	.15	57.8	.18	57.1	.18	57.5	.18	55.7	.17	56.3	.17
11	57.5	57.0	.10	57.8	.13	57.2	.13	57.7	.13	56.1	.13	56.7	.12
12	56.8	55.5	.14	56.9	.19	56.2	.18	56.4	.18	54.9	.18	54.2	.18
13	56.2	54.3	.10	56.3	*	55.4	*	55.7	*	55.0	*	54.7	*
14	56.4	56.0	.02	57.2	.03†	56.7	.03†	57.3	.03†	56.6	.03†	56.8	.03†
15	55.9	56.0	.10	57.1	.14	56.2	.13	56.8	.15	55.9	.14	56.0	.13
16	57.1	57.6	.10	58.8	.12	57.4	.12	58.2	.12	56.8	.12	57.3	.11
17	56.9	57.5	.07	58.8	.10	57.5	.09	58.3	.09	57.0	.09	57.3	.06
18	57.9	57.8	.07	57.8	.09	56.4	.09	57.5	.10	57.8	.09	58.3	.10
19	57.9	57.9	.03	58.5	.05	57.6	.04	58.4	.04	58.1	.06	58.3	.04
20	58.0	58.1	.06	58.9	.07	57.7	.06	58.8	.07	58.0	.06	58.5	.07
21	57.4	58.5	.01	58.5	.04	58.2	.04	58.4	.04	58.4	.05	58.6	.04
22	56.3	56.3	.20	57.2	.18	56.5	.16	56.8	.19	55.0	.19	54.6	.18
23	56.6	55.7	.11	56.5	.13	56.1	.16	56.0	.16	54.9	.14	54.7	.13
24	56.0	54.9	.10	55.7	.13	55.3	.12	55.3	.12	53.8	.09	53.4	.09
25	55.0	54.4	.09	55.3	.12	54.8	.11	54.7	.12	53.4	.10	53.1	.10
26	56.0	56.0	.06	56.7	.10	55.8	.11	56.3	.10	55.1	.05	55.5	.08
27	55.4	55.7	.07	56.2	.11	55.4	.09	55.8	.11	55.0	.09	55.4	.08
28	54.8	54.3	.04	55.2	.06	55.0	.06	55.0	.06	54.8	.05	54.9	.05
29	54.7	54.1	.00	54.7	.00	54.7	.00	54.7	.00	54.3	.00	54.3	.00
30	54.6	53.3	.03	54.4	.04†	53.8	.04†	53.7	.04†	52.0	.04†	52.0	.04†
31	53.4	51.4	.19	53.2	.23	53.7	.24	52.5	.24	50.1	.20	49.6	.19
Total...	....	....	3.07	....	3.47	....	3.39	....	3.50	....	3.12	....	3.05
Mean ..	57.6	57.0	0.10	58.0	0.12 28 days.	57.4	0.12 28 days.	57.7	0.12 28 days.	56.5	0.11 28 days.	56.5	0.11 28 days.

October.		Mean Temp.	Total Evap.
28 days	Res. ..	57.3	....
	No 1..	56.6	2.79
	No. 2..	57.7	3.47
	No. 3..	57.0	3.39
	No 4..	57.3	3.50
	No. 5..	56.1	3.12
	No. 7..	56.1	3.05

* No observation. † Assumed.

TABLE No. 3.

Hourly Observations May 19–20, 1885.

Date.	Time.	Temperature at Surface—Fahr.		Evaporation, Inches.		Temp. of Air.	Dew Point.	Force of Vapor.	Relative Humidity.
		Res.	Tank No. 1.	Tank No. 1.	Tank No. 3.				
1885.									
May 19	5 P.M.	64.0	68.9	.....	.....	83.0	75.0	0.455	39.9
	6	63.1	68.0	0.007	0.005	74.0	61.0	0.542	60.3
	7	64.2	66.7	0.008	0.005	75.0	52.0	0.391	46.5
	8	63.1	65.3	0.007	0.010	71.0	52.0	0.387	51.0
	9	61.3	64.0	0.008	0.010	68.0	54.0	0.400	58.0
	10	61.3	63.5	0.009	0.000	67.0	54.0	0.413	62.0
	11	61.3	62.6	0.009	0.010	63.0	55.0	0.430	75.0
	12	61.5	62.1	0.009	0.000	63.0	54.0	0.415	72.3
May 20	1 A.M.	61.3	61.7	0.004	0.010	60.5	54.0	0.412	77.4
	2	61.3	61.7	0.005	0.000	59.0	54.5	0.432	85.0
	3	61.3	61.5	0.004	0.010	62.5	55.5	0.438	77.4
	4	61.3	61.2	0.005	0.000	59.5	54.0	0.426	82.2
	5	61.3	60.8	0.005	0.005	61.3	53.0	0.400	72.3
	6	61.0	60.8	0.005	0.005	61.0	53.0	0.403	74.3
	7	60.4	60.8	0.003	0.005	61.0	54.0	0.407	74.8
	8	60.3	60.8	0.004	0.005	60.0	47.0	0.322	60.5
	9	59.5	61.2	0.007	0.020	59.0	50.0	0.372	75.8
	10	59.0	61.0	0.017	0.010	57.7	46.5	0.320	64.6
	11	58.3	61.7	0.017	0.005	58.3	49.0	0.351	70.3
	12	59.5	61.7	0.016	0.005	56.5	47.0	0.399	71.8
	1 P.M.	58.3	61.7	0.011	0.020	56.0	46.0	0.308	66.3
	2	61.0	61.7	0.011	0.005	58.0	46.0	0.310	59.9
	3	61.0	61.7	0.011	0.005	58.8	46.0	0.308	59.7
	4	61.0	61.7	0.011	0.010	58.0	45.5	0.303	59.5
	5	60.4	61.3	0.011	0.005	57.0	46.0	0.309	64.1
Total		1 526.0	1 564.1	0.204	0.165	1 568.1	1 304.0	9.653	1 660.9
Mean		61.0	62.6	0.0085	0.0069	62.4	51.8	0.386	67.0
Means	Night	62.0	63.7	0.0067	0.0054	66.2	55.3	0.426	66.9
	Day	60.0	61.3	0.0103	0.0083	58 6	48.3	0 346	67.1

TABLE No. 3.—(*Continued.*)

HOURLY OBSERVATIONS JUNE 23–24, 1885.

Date.	Time.	Temperature at Surface—Fahr.				Evaporation, Inches.			Temp. of Air.	Dew Point.	Force of Vapor.	Relative Humidity	Wind.
		Res	Tank No. 1.	Tank No. 2.	Tank No. 3.	Tank No. 1.	Tank No. 2.	Tank No. 3.					Miles Per Hour.
1885. June 23.....	5 P.M....	71.4	70.5	71.0	70.5	.....	.....	.....	69.0	44.0	0.291	41.0	.....
	6	70.9	70.0	70.9	70.2	0.020	0.010	0 005	66.0	41.0	0.259	40.0	11 5
	7	71.1	70.0	70.5	70.0	0 011	0.020	0.025	62.8	43.0	0.281	49.0	10.1
	8	70.7	69.8	70.3	69.6	0.011	0.010	0.010	58.0	46.0	0.309	64.0	5.7
	9	70.5	69.6	70.3	69.6	0.013	0.010	0 015	56.8	47.0	0.311	68.0	3.3
	10	70.5	69.4	70.3	69.4	0.020	0.020	0.015	57.0	45.0	0.304	66.0	4.4
	11	70.3	69.3	70.0	69.1	0.020	0.030	0.030	57.8	43.0	0.284	60.0	7.3
	12	70.2	69.1	70.0	68.9	0.020	0.030	0.010	56.3	43.0	0.278	62.0	7.6
June 24.....	1 A.M....	70.2	68.9	69.8	68.5	0.020	0.010	0.020	54.5	45.0	0.301	71.0	6.8
	2	70.0	68.7	69.6	68.7	0.020	0.020	0.030	56.1	46.0	0.307	68.0	6.3
	3 ...	69.6	68.5	69.4	68.7	0.020	0.030	0.020	56.8	43.5	0.279	60.0	8.7
	4	69.4	68.2	69.3	68.4	0.022	0.020	0.020	56.7	39.0	0.228	51.0	12.9
	5	69.3	68.2	69.3	68.4	0.022	0.040	0.020	56.7	39.0	0.246	54.0	13.8
	6	69.3	68.0	69.1	68.2	0.021	0.020	0.030	59.0	42.0	0.269	54 0	15.5
	7	69.1	67.8	69.1	68.2	0.015	0.010	0.030	61.5	42.5	0.266	50.0	12.4
	8	69.1	67.8	69.1	68.5	0.015	0.030	0.020	64.2	44.0	0.285	48.0	16.6
	9	69.3	68.2	69.1	68.9	0.015	0.020	0 020	67.0	43.0	0.274	41.0	18.6
	10	59.3	68.2	69.4	69 3	0.015	0.020	0.020	69.5	44.5	0.299	42.0	19.1
	11	69.6	68.5	70.0	69.6	0.015	0.030	0.020	71.5	42.0	0.289	37.0	15.0
	12	69.8	68.7	70.5	70.2	0.010	0.010	0.020	74.2	45.0	0.301	36.0	20.6
	1 P.M....	70.0	69.3	70.9	70.5	0.018	0.040	0.030	76.0	45 0	0.305	34.0	17.4
	2	70.2	69.8	71.1	70.7	0.018	0.010	0.020	79.5	46.5	0.322	32.0	16.0
	3	70.5	70.2	70.9	70.7	0.019	0.020	0.020	79.3	47.5	0.328	33.0	13.7
	4	70.3	70.0	70.5	70.3	0.020	0.020	0.020	78.3	48.0	0.342	38.0	11.8
	5	70.3	70.0	70.2	70.0	0.020	0.020	0.020	79.0	53.5	0.412	41.0	10.0
Total		1 750.9	1 726.7	1 750.6	1 735.1	0.420	0.500	0.490	1 623.5	1 108.0	7.370	1 240.0	285.1
Mean		70.0	69.0	70.0	69.4	0.0175	0.0208	0.0204	64.5	44.1	0.292	50.0	11.9
Means	Night.....	70.3	69.2	70.0	69.2	0.0182	0.0208	0.0183	58.5	43.6	0.284	58 9	8.2
	Day	69.7	68.8	70.0	69.5	0.0168	0.0208	0.0225	70.6	44.7	0.300	41 1	15.6

TABLE No. 3.—(*Continued.*)

HOURLY OBSERVATIONS JUNE 24–25, 1885.

Date.	Time.	Temperature at Surface—Fahr. Res.	Tank No. 1.	Tank No. 2.	Tank No. 3.	Evaporation, Inches. Tank No. 1.	Tank No. 2.	Tank No. 3.	Temp. of Air.	Dew Point.	Force of Vapor.	Relative Humidity	Wind. Miles Per Hour.
1885.	5 P.M....	70.3	70.0	70.2	70.0	.....	.....	.....	79.0	52.5	0.412	41.0	.....
June 24.....	6	70.2	69.8	69.8	69.6	0.010	0.010	0.005	75.5	56.5	0.459	52.0	5.8
	7	70.0	69.8	70.0	69.8	0.006	0.000	0.000	67.2	56.0	0.464	71.0	2.2
	8	70.0	69.3	69.4	69.3	0.006	0.010	0.005	63.9	54.0	0.420	71.0	2.6
	9	70.0	69.6	69.4	69.8	0.008	0.000	0.000	63.5	54.0	0.409	70.0	3.4
	10	69.8	68.9	69.1	69.4	0.013	0.030	0.030	61.5	54.5	0.420	77.0	4.5
	11	69.8	69.1	68.9	69.4	0.013	0.010	0.010	60.0	52.0	0.396	76.0	6.0
	12	69.1	68.4	68.4	69.1	0.014	0.010	0.020	58.5	52.5	0.401	81.0	8.1
June 25.....	1 A.M....	69.8	68.4	68.7	68.7	0.011	0.030	0.020	58.0	52.0	0.393	82.0	8.1
	2	69.4	68.4	68.7	68.4	0.012	0.000	0.000	56.0	52.0	0.391	87.0	8.8
	3	69.4	68.0	69.1	68.7	0.012	0.000	0.000	55.0	51.0	0.376	87.0	5.3
	4	68.7	68.2	68.7	68.4	0.008	0.020	0.020	54.0	50.0	0.362	87.0	3.7
	5	69.1	68.0	68.7	68.2	0.008	0.010	0.020	57.5	51.5	0.386	81.0	7.9
	6	68.9	68.0	68.7	68.2	0.009	0.020	0.010	63.0	54.0	0.416	72.0	6.8
	7	69.1	68.2	68.7	68.5	0.008	0.010	0.000	69.0	56.0	0.446	63.0	5.9
	8	69.1	68.5	69.1	68.9	0.008	0.010	0.020	72.8	56.0	0.438	54.0	6.4
	9	69.6	69.4	70.2	70.0	0.009	0.030	0.015	76.4	55.5	0.444	49.0	8.4
	10 ...	70.0	71.2	71.4	70.9	0.017	0.010	0.015	80.0	54.0	0.417	41.0	7.0
	11	70.5	72.1	72.0	71.4	0.016	0.010	0.010	82.1	49.0	0.364	33.0	11.2
	12	70.5	73.2	72.5	72.0	0.017	0.010	0.025	85.0	56.0	0.449	37.0	12.7
	1 P.M....	71.8	73.8	73.2	72.3	0.010	0.020	0.005	85.1	55.0	0.438	36.0	9.0
	2	72.0	74.3	73.2	72.5	0.010	0.010	0.030	86.0	54.0	0.425	34.0	10.6
	3	72.5	74.8	73.4	72.7	0.010	0.020	0.025	87.0	57.0	0.467	36.0	9.9
	4	72.1	74.1	72.5	72.3	0.020	0.030	0.010	86.1	56.0	0.457	36.0	9.2
	5	72.0	73.6	71.8	72.0	0.015	0.010	0.025	84.0	55.0	0.437	38.0	9.7
Total.....		1753.7	1757.1	1755.8	1750.5	0.270	0.320	0.320	1766.1	1346.0	10.487	1492.0	173.2
Mean.....		70.1	70.2	70.2	70.0	0.0113	0.0133	0.0133	70.2	53.8	0.419	60.5	7.2
Means	Night.....	69.6	68.9	69.1	69.1	0.0101	0.0108	0.0108	61.8	53.0	0.408	75.2	5.6
	Day.....	70.5	71.5	71.2	70.8	0.0124	0.0158	0.0158	78.6	54.6	0.431	45.9	8.8

TABLE No. 3.—(*Continued.*)

HOURLY OBSERVATIONS JULY 8–9, 1885.

Date.	Time.	Temperature at Surface, Fahr.						Evaporation, Inches.					Temp. of Air.	Dew Point.	Force of Vapor. Inches.	Relative Humidity. Per cent.	Wind.	
		Reservoir.	Tank No. 1.	Tank No. 2.	Tank No. 3	Tank No. 5.	Tank No. 6.	Tank No. 1.	Tank No. 2.	Tank No. 3.	Tank No. 5.	Tank No 6.					Miles per Hour.	Direction.
1885.																		
July 8	5 P.M.	81.9	83.1	82.4	82.0	82.2	82.4	.....	....	.....	.....	....	86.5	72.0	0.821	55.6	.....	
	6	81.9	82.2	81.9	81.7	81.7	82.0	0.002	0.010	0.010	0.010	0.010	79.0	75.0	0.860	78.7	1.5	S. W.
	7	81.9	81.5	81.1	81.1	80.8	80.8	0.006	0.010	0.010	0.020	0.010	74.0	71.0	0.763	85.0	1.8	"
	8	81.1	80.4	80.8	81.0	79.7	79.7	0.004	0.010	0.010	0.000	0.020	73.5	68.0	0.686	83.2	3.2	"
	9	80.8	79.7	80.4	80.2	78.8	78.8	0.010	0.010	0.010	0.010	0.020	69.5	67.0	0.655	89.6	3.2	"
	10	80.2	78.8	79.9	79.9	78.1	78.1	0.010	0.025	0.025	0.015	0.010	70.0	63.0	0.639	87.0	4.2	"
	11	79.7	78.3	79.7	79.3	77.7	77.5	0.019	0.005	0.015	0.015	0.000	69.5	67.0	0.650	89.0	3.7	"
	12	79.3	77.7	79.3	79.0	77.2	77.5	0.010	0.020	0.000	0.020	0.015	70.5	65.0	0.610	81.0	3.7	"
July 9	1 A.M.	79.0	77.5	78.8	78.3	76.6	76.6	0.010	0.020	0.025	0.010	0.015	69.0	64.0	0.615	86.5	5.0	"
	2	78.6	77.0	78.4	77.9	76.3	76.5	0.010	0.010	0.005	0.010	0.005	68.0	65.0	0.612	89.5	5.6	"
	3	78.3	76.8	78.3	77.7	76.1	75.9	0.015	0.015	0.020	0.010	0.015	68.0	65.0	0.612	89.5	5.5	"
	4	77.9	76.6	78.1	77.5	75.9	75.9	0.015	0.010	0.000	0.005	0.020	66.5	65.0	0.600	91.5	5.2	"
	5	77.7	76.5	77.7	77.2	75.4	75.7	0.009	0.015	0.020	0.015	0.000	68.5	66.0	0.634	91.0	5.9	"
	6	77.4	76.3	77.5	76.8	75.7	76.1	0.011	0.020	0.010	0.020	0.010	72.5	68.0	0.673	83.0	6.0	"
	7	77.2	76.3	77.4	76.8	76.5	76.5	0.010	0.010	0.020	0.009	0.010	76.5	69.0	0.718	77.4	7.1	"
	8	77.2	76.6	77.7	77.4	77.5	77.7	0.010	0.000	0.000	0.000	0.000	80.5	72.0	0.780	73.0	6.4	"
	9	78.1	78.3	79.9	78.8	79.9	79.9	0.010	0.000	0.000	0.010	0.000	85.5	74.0	0.835	65.0	5.7	"
	10	79.5	80.2	80.8	80.6	82.0	81.9	0.003	0.020	0.000	0.010	0.020	88.0	72.0	0.778	59.0	5.8	"
	11	79.5	81.9	83.1	81.3	83.1	82.8	0.010	0.020	0.020	0.010	0.010	90.0	74.0	0.820	55.0	6.8	"
	12	80.8	83.1	83.1	81.9	82.9	82.8	0.002	0.000	0.030	0.000	0.020	90.5	71.0	0.762	50.0	7.5	"
	1 P.M.	80.2	83.5	82.9	81.9	83.1	82.8	0.010	0.040	0.020	0.000	0.030	90.5	73.0	0.807	53.0	9.0	S. S. W.
	2	81.0	83.5	83.1	82.0	82.9	82.8	0.015	0.010	0.000	0.020	0.020	89.7	72.0	0.780	54.0	12.9	"
	3	79.5	82.6	82.0	81.5	81.7	81.7	0.020	0.020	0.030	0.010	0.020	89.0	72.0	0.780	54.0	11.6	"
	4	80.4	82.2	81.1	80.8	80.8	81.0	0.010	0.020	0.030	0.040	0.030	87.0	72.0	0.772	57.0	8.7	W.
	5	80.6	81.7	80.6	80.4	80.1	80.2	0.020	0.000	0.010	0.030	0.065	75.0	65.0	0.628	72.0	12.3	"
Total		1989.7	1992.3	2066.0	1993.0	1982.7	1983.6	0.242	0.320	0.320	0.290	0.315	1947.2	1727.0	17.890	1849.5	148.3	
Means		79.5	79.6	80.2	79.6	79.2	79.3	0.0101	0.0133	0.0133	0.0121	0.0131	77.8	69.1	0.715	74.4	6.2	
Means	Night	79.9	78.9	79.7	79.4	78.1	78.2	0.0092	0.0133	0.0125	0.0117	0.0117	71.2	67.0	0.669	85.3	4.0	
	Day	79.2	80.3	80.6	79.8	80.3	80.3	0.0109	0.0133	0.0141	0.0125	0.0146	84.3	71.2	0.761	63.5	8.3	

TABLE No. 3.—(*Continued.*)

HOURLY OBSERVATIONS JULY 9-10, 1885.

Date.	Time.	Temperature at Surface, Fahr.						Evaporation, Inches.					Temperature of Air.	Dew Point.	Force of Vapor. Inches.	Relative Humidity. Per cent.	Wind.	
		Reservoir.	Tank No. 1.	Tank No. 2.	Tank No. 3.	Tank No. 5.	Tank No. 6	Tank No. 1.	Tank No. 2.	Tank No. 3.	Tank No. 5	Tank No. 6.					Miles per Hour.	Direction.
July 9	5 P.M.	80.6	81.7	80.6	80.4	89.1	80.2	.....	.....	.....	.....	.....	75.0	65.0	0.628	72.0	.....	.....
	6	79.0	79.3	79.0	78.8	77.0	77.0	0.000	0.000	0.000	0.000	0.000	69.0	67.0	0.575	64.0	12.4	S. W.
	7	78.8	78.8	78.8	78.4	77.0	77.0	0.000	0.000	0.000	0.000	0.000	68.0	67.0	0.648	95.0	6.3	"
	8	78.8	78.4	78.8	78 3	76.6	76.6	0.010	0.000	0.000	0.000	0.000	67.5	66.0	0.648	95.0	4.9	"
	9	78.6	78.3	78.6	78.1	76.6	76.3	0.115	0.030	0.020	0.000	0.010	69.5	66.0	0.665	92.0	4.1	"
	10	78.4	78.1	78.4	77.9	76.3	76.5	0.010	0.000	0.010	0.010	0.010	70.0	67.0	0.658	90.0	4.5	"
	11	78.4	77.7	78.3	77.7	76.3	76.3	0.015	0.010	0.010	0.040	0.020	71.0	68.0	0.680	88.0	5.2	W.
	12	78.3	77.7	78.1	77.5	76.5	76.5	0.010	0.030	0.010	0.010	0.030	71.5	68.0	0.675	87.0	6.7	"
July 10	1 A.M.	77.9	77.4	77.9	77.4	76.1	76.3	0.005	0.000	0.010	0.000	0.000	70.0	67.0	0.660	90.0	2.7	"
	2	77.7	77.2	77.7	77.0	75.6	75.6	0.015	0.010	0.010	0.010	0.010	70.0	65.0	0.622	85.0	2.5	S. W.
	3	77.5	77.0	77.5	76.8	75.6	75.6	0.005	0.010	0.020	0.000	0.000	70.5	65.0	0.622	85.0	4.7	"
	4	77.5	76.8	77.4	76.6	75.7	75·7	0.010	0.010	0.020	0.010	0.010	70.0	65.0	0.622	85.0	4.2	"
	5	77.2	76.6	77.0	76.6	75.4	75.4	0.005	0.020	0.010	0.020	0.010	70.5	66·0	0.644	85.0	6.3	"
	6	76.8	76.3	76 8	76.5	75.4	75.4	0.014	0.010	0.010	0.010	0.010	71.0	66.0	0.660	85.0	6.4	"
	7	76.8	76.5	76.8	76.5	75.9	75.9	0.006	0.010	0.000	0.000	0.000	73.0	68.0	0.680	81.0	6.2	"
	8	77.0	76.5	77.0	76.8	76.6	76.6	0.004	0.020	0.020	0.020	0.010	77.5	69.0	0.700	72.0	7 2	"
	9	77.2	77.0	77.9	77.5	77.9	77.9	0.011	0.020	0.015	0.025	0.030	79.5	66.0	0.887	76.7	11.4	W.
	10	77.5	77.4	78.3	77.9	78.3	77.9	0.020	0.020	0.025	0.015	0.015	79.5	68.0	0.650	64.0	12.0	"
	11	77.5	77.4	77.9	77.9	77.7	77.7	0.010	0.020	0.015	0.020	0.025	79.0	65.0	0.612	62.0	16.7	"
	12	77.5	77.4	77.7	77.7	77.7	77.7	0.010	0.015	0.015	0.025	0.015	79.5	68.0	0.677	66.0	13.3	"
	1 P.M.	77.5	77.9	79.0	78.4	79.0	78.4	0.010	0.010	0.010	0.015	0.005	82.0	68.0	0.677	60.0	9.6	"
	2	78 1	79.0	79.7	79.0	79.9	79.7	0.000	0.005	0.010	0.010	0.010	84.0	69.0	0.720	58.0	10.3	"
	3	78.6	79.2	79.3	79.0	79.3	79.3	0.035	0.030	0.040	0.035	0.040	83.0	63.0	0.610	51.0	13.4	"
	4	78.4	79.0	79.0	78.6	78.4	78.3	0.010	0.020	0.020	0.015	0.015	82.5	63.0	0.577	48.0	11.2	N. W.
	5	78.3	78.8	78.3	78.3	77.5	77.7	0.025	0.020	0.010	0.030	0.025	80.0	63.0	0.585	55.0	8.9	W.
Total		1949.9	1947.4	1955.8	1945.6	1928.4	1928.7	0.255	0.320	0.310	0.320	0.300	1863.0	1658.0	16.382	1891.7	191.1	
Mean		77.9	77.8	78.2	77.7	77.1	77.1	0.0106	0.0133	0.0130	0.0133	0.0125	74.4	66.4	0.657	76.2	8.0	
Means	Night	78.3	77.9	78.4	77.7	76.4	76.4	0.0083	0.0100	0.0100	0.0083	0.0083	70.0	66.4	0.643	86.2	5.4	
	Day	77.5	77.6	78.1	77.7	77.7	77.7	0.0130	0.0166	0.0158	0.0183	0.0166	78.8	66.4	0.672	61.1	10.6	

July 9th, at 4.30 P.M., sun obscured and thunder suddenly heard; at 5.15 P.M. a very heavy storm struck the reservoir, with violent wind, thunder and lightning, and rain, but at 6 P. M. passed over and cleared.

TABLE No. 3.—(*Continued.*)

HOURLY OBSERVATIONS JULY 10–11, 1885.

Date.	Time.	Temperature at Surface, Fahr.						Evaporation, Inches.					Temperature of Air.	Dew Point.	Force of Vapor. Inches.	Relative Humidity. per cent.	Wind.	
		Reservoir.	Tank No. 1.	Tank No. 2.	Tank No. 3	Tank No. 5.	Tank No. 6.	Tank No. 1.	Tank No. 2.	Tank No. 3	Tank No. 5.	Tank No. 6.					Miles per Hour.	Direction.
July 10	5 P.M	78.3	78.8	78.3	78.3	77.5	77.7	.....	.....	.....	.....	.....	80.0	63.0	0.585	55.0	.....	.....
	6	78.3	78.3	78 3	77.9	76.8	76.6	0.012	0.010	0.010	0.000	0.010	76.0	63.0	0.608	66.6	7.3	W.
	7	77.9	78.1	77.9	77.0	75.7	75.9	0.020	0.020	0.040	0.030	0.010	71.5	64.0	0.566	73.3	11.0	N.W.
	8	77.9	77.5	77.5	76.8	75.6	75.7	0.013	0.020	0.000	0.020	0.030	68.9	62 0	0.564	79.6	7.3	W.
	9	77.7	77.2	77.4	76.6	75.2	75.2	0.014	0.000	0.030	0.010	0.000	67 0	63.0	0.549	81.7	7.1	W.N.W.
	10	77.5	77.0	77.0	76.5	74.8	75.0	0.006	0.030	0.000	0.010	0.020	65.5	63.0	0.549	89.0	8.1	W.N.W.
	11	77.4	76.8	77.0	76 6	74.7	74.8	0.025	0.010	0.010	0.000	0.000	64.0	60.0	0.529	88.8	6.1	N.W.
	12	77.0	76.5	77.0	76.3	74.5	74.5	0.010	0.020	0.010	0.020	0.000	62.5	61.0	0.517	91.3	6.6	N.W.
July 11	1 A.M	76.8	76.3	76.6	75 6	74.1	74.3	0.010	0.000	0.000	0.000	0.010	63.0	60.0	0.510	88 6	3.8	W.
	2	76.6	76.1	76.5	75.7	73.8	74.1	0.007	0.010	0.040	0 020	0.020	63.0	60.0	0.503	85.9	6.0	W.N.W.
	3	76.3	75.9	76.3	75.6	73.8	73.8	0.018	0.030	0.000	0.000	0.000	62.4	60.0	0.517	91.3	7.3	N.W.
	4	76.1	75.6	76.1	75.4	73.8	73.8	0.005	0.010	0.010	0.010	0.020	61.5	58.0	0.491	88.4	5.0	"
	5	76.1	75.4	76.1	75.0	73.6	73.6	0.010	0 030	0.010	0.020	0.010	63.0	60.0	0.503	85.9	6.5	"
	6	75.7	75.0	76.9	75.2	73.9	74.3	0.018	0.000	0.005	0.000	0.000	66.0	61.0	0.536	82.8	6.2	"
	7	75.7	75.4	75.7	75.7	74.7	75.0	0.012	0.010	0.015	0.010	0.010	72.0	62.0	0.550	75.1	8.1	N.N.W.
	8	76.3	75.6	76.3	76 1	75.9	75.9	0.010	0.000	0.000	0.010	0.000	72.5	61.0	0.545	67.2	8.0	N.W.
	9	76 6	75.9	77.0	76.6	77.2	77.4	0.010	0.010	0.005	0.010	0.010	75.0	65.0	0.542	60.3	7.3	"
	10	77.0	76.6	78.1	77.4	78.1	78.4	0.010	0.010	0.025	0.020	0.020	76.5	62.0	0.557	59.1	8.3	"
	11	77.4	77.7	79.5	78.6	80.2	80.2	0.010	0.015	0.000	0.010	0.010	78.5	63.0	0.567	56.4	4.6	"
	12	78.3	79.0	79.7	79.0	79.7	79.7	0.000	0.015	0.020	0.020	0.020	77.0	64.0	0.595	63.0	5.3	N.
	1 P.M	79.2	79.7	80.6	79.5	80.6	80.8	0.010	0.005	0.020	0.020	0.015	79.0	64.0	0.592	56.9	6.8	"
	2	79.3	80.4	81.0	79.9	80.6	81.0	0.010	0.005	0.010	0.010	0.015	79.0	64.0	0.598	58.5	7.0	N.N.W.
	3	79.7	80.2	80.1	79.7	79.9	79.9	0.015	0.020	0.005	0.025	0.045	76.5	63.0	0.574	58 0	6.4	E.
	4	79.9	79 9	79.9	79.7	79.3	79.5	0.010	0.020	0.015	0.010	0.000	77.5	60.0	0.510	53.0	6.2	"
	5	79.5	79.2	79.5	79.5	78.4	78.4	0.015	0.010	0.020	0.015	0.015	73.0	60.0	0.550	65.5	8.0	N.E.
	Total	1938.5	1934.1	1946.3	1930.2	1912.4	1915.5	0.280	0.310	0.300	0.300	0.290	1770.8	1546.0	13.707	1822.2	164.3	
	Mean	77.5	77.3	77.8	77.1	76.4	76.5	0.0117	0.0130	7.0125	0.0125	0.0121	70.6	61.8	0.547	73.4	6.8	
Means	Night	.....	77.2	76.9	77.1	76.4	74.9	74.9	0.0125	0.0158	0.0133	0.0117	0.0168	66.4	61.3	0.537	82.9	6.8
	Day	.....	77.7	77.7	78.5	77.9	78.0	78.2	0.0108	0.0100	0.0117	0.0133	0.0133	74.8	62 4	0.558	63.9	6.8

TABLE No. 3.—(*Continued.*)

HOURLY OBSERVATIONS AUGUST 7–8, 1885.

Date.	Time.	Temperature at Surface, Fahr.							Evaporation, Inches.						Temp. of Air.	Dew Point.	Force of Vapor, Inches.	Relative Humidity, Per cent.	Wind.	
		Reservoir.	Tank No. 1.	Tank No. 2.	Tank No. 3.	Tank No. 4.	Tank No. 5.	Tank No. 7.	Tank No. 1.	Tank No. 2.	Tank No. 3.	Tank No. 4.	Tank No. 5.	Tank No. 7.					Miles per Hour.	Directions.
1885.																				
Aug. 7	6 P.M.	75.2	75.6	75.0	74.8	74.8	72.8	72.4	.....	.....	.....	.....	.....	.....	66.0	60.0	0.320	81.3	.....	.....
	7	75.5	75.2	75.0	74.6	74.7	73.0	72.8	0.010	0.010	0.010	0.010	0.010	0.005	65.0	61.0	0.532	86.3	2.9	S. E.
	8	75.5	74.8	75 1	74.7	74.7	73.1	73.1	0.020	0.020	0.015	0.010	0.015	0.020	64.9	60.0	0.515	83.6	3.1	"
	9	75.3	74.4	75.0	74.6	74 6	73.0	72.6	0.010	0.000	0.005	0.000	0.005	0.005	64.8	60.0	0.516	83.6	3.4	E.
	10	75.1	74.4	74.9	74.5	74.5	73.2	72.7	0.005	0.010	0.015	0.015	0.010	0.005	64.5	61.5	0.553	92.6	2.0	"
	11	75.1	74.2	74.9	74.5	74.5	73.1	72.8	0.015	0.010	0.005	0.010	0.000	0.010	64 0	61.5	0.546	91.6	1.3	"
	12 ...	74 9	74.1	74.9	74.4	74.4	73.1	72.9	0.005	0.000	0.010	0.005	0.010	0.010	63.3	60.5	0.520	88.7	1.2	"
Aug. 8	1 A.M.	74.8	74.0	74.7	74.2	74.2	73.2	72.8	0.010	0.000	0.000	0.000	0.000	0.000	62.2	62.0	0.554	99.4	0.5	"
	2	74.7	73.8	74.6	74.0	74.2	72.8	72.4	0.010	0.010	0.000	0.000	0.000	0.000	63.0	63.0	0.576	100.0	1.8	"
	3	74.6	73.8	74 4	73.8	74.0	72.2	72.2	0.010	0.005	0.000	0.000	0.000	0.010	62.0	60.0	0.523	94.2	2.0	S. E.
	4	74.4	73.8	74.4	73.8	73.8	72.4	72.2	0.010	0.000	0.010	0.010	0.000	0.000	62.0	62.0	0.556	100.0	1.0	N. W.
	5	74.0	73.6	74.0	73.6	73.2	71.8	71.8	0 010	0.015	0.000	0.010	0.010	0.010	60.5	60.5	0.528	100.0	2.0	"
	6	74.0	73.6	74.0	73.6	73.6	72.0	72.0	0.010	0.010	0.015	0.010	0.010	0.010	60.7	60.7	0.531	100.0	2.0	N.
	7 ...	74.3	73.6	74.3	73.9	74.0	73.1	72.0	0.000	0.010	0.005	0.010	0.010	0.010	66.8	64.5	0.600	91.9	2.0	N. E.
	8	74.6	73.8	74.2	74.2	74.4	73.8	74.0	0.015	0.010	0.000	0.000	0.000	0.000	75.0	64.5	0.609	70.2	4.5	E.
	9	74.8	74.4	75.0	74.8	75.0	75.0	75.0	0.005	0.010	0.020	0.020	0.025	0.010	78.5	66.0	0.619	63.5	5.2	"
	10	75.0	74.5	75.4	75.2	75.2	75.4	75.3	0.010	0.025	0.035	0.025	0.020	0.025	75.8	59.0	0.505	56.3	8.2	"
	11	75.2	75.0	76.1	75.6	75.8	76.2	75.8	0.020	0.010	0.005	0.010	0.020	0.005	80.0	60.0	0.524	51 2	8.8	"
	12	75.5	76.0	77.0	76.2	76.4	77.3	77.1	0.015	0.015	0.020	0.020	0.015	0.020	76 5	59.5	0.500	55.0	6.2	"
	1 P.M.	75.8	76.6	77.2	76.4	76.6	77.4	77.2	0.015	0.020	0.000	0.020	0.025	0.010	77.0	56.0	0.457	49.3	6.3	"
	2	76.0	76.8	76.7	76.4	76.4	76.7	76.5	0.020	0.020	0.040	0.035	0.025	0.030	77.5	57.0	0.467	49.6	7.7	"
	3	76.0	76.9	76.3	76.2	76.2	75.9	75.7	0.010	0.010	0.015	0.000	0.010	0.025	76.8	60.0	0.510	55.0	8.1	"
	4	76.0	76.7	75.8	75.8	76.0	75.0	75.0	0.015	0.020	0.020	0.025	0.030	0.005	76.8	61.0	0.534	58.6	7.2	"
	5	75.8	76.4	75.8	75.6	75.6	74.4	74.1	0.015	0.010	0.015	0.005	0.005	0.020	74.8	62.0	0.550	63.8	4.4	"
	6	75.7	76.1	75.6	75.2	75.3	73.8	73.2	0.020	0.010	0.000	0.010	0.005	0.005	74.8	62.0	0.554	63.9	3.2	"
Total		1877.8	1872.1	1880.3	1870.6	1872.1	1849.7	1843.6	0.285	0.260	0.260	0.260	0.260	0.250	1733.2	1524.2	13.199	1929.6	95.0	
Mean		75.1	74.8	75.2	74.8	74.9	74.0	73.8	0.0119	0.0108	0.0108	0.0108	0.0108	0.0104	69 3	61.0	0.532	77.4	4.0	
Means	Night	74.9	74.2	74.7	74.2	74.2	72.8	72.5	0.0104	0.0075	0.0071	0.0066	0.0058	0.0071	63.3	61.0	0.529	92.6	2.0	
	Day	75.3	75.4	75.7	75.4	75.5	75.3	75.0	0.0134	0.0142	0.0146	0.0150	0.0158	0.0137	75.3	60.9	0.535	62.2	6.0	

TABLE No. 3.—(*Continued.*)

HOURLY OBSERVATIONS.—SEPTEMBER 11–12, 1885.

Date.	Time.	Temperature at Surface, Fahr.							Evaporation, Inches.						Temp. of Air.	Dew Point.	Force of Vapor. Inches.	Relative Humidity. Per cent.	Wind.	
		Reservoir.	Tank No. 1.	Tank No. 2.	Tank No. 3.	Tank No. 4.	Tank No. 5.	Tank No. 7.	Tank No. 1.	Tank No. 2.	Tank No. 3.	Tank No. 4.	Tank No. 5.	Tank No. 7.					Miles per Hour.	Direction.
1885.																				
Sept. 11.....	6 P. M.	66.1	65.7	65.8	65.4	65.4	63.6	63.1	.....	.....	.....	.....	.....	.....	55.5	50.0	0.370	83.9	.....	S. E.
	7	65.9	65.0	65.6	65.1	65.1	62.8	62.0	0.000	0.010	0.005	0.000	0.005	0.025	51.0	47.0	0.321	85.9	2.5	"
	8	65.5	64.6	65.4	64.7	64.7	62.4	61.4	0.010	0.010	0.010	0.010	0.010	0.010	51.2	47.0	0.321	85.9	3.0	"
	9	65.5	64.4	65.2	64.6	64.5	62.5	61.3	0.010	0.010	0.010	0.010	0.005	0.000	49.0	46.0	0.309	88.9	1.6	S. W.
	10	65.4	64.2	65.1	64.5	64.4	62.3	61.2	0.010	0.010	0.000	0.005	0.000	0.015	48.0	47.0	0.323	96.2	1.3	"
	11	65.3	63.7	65.0	64.2	64.2	61.6	60.2	0.010	0.010	0.015	0.005	0.000	0.010	47.5	45.5	0.304	92.4	4.4	"
	12	65.2	63.7	64.8	64.0	64.0	61.4	60.1	0.010	0.010	0.005	0.010	0.010	0.005	45.5	43.5	0.341	96.3	4.1	"
Sept. 12.....	1 A. M.	65.2	63.8	64.8	63.8	63.8	61.4	60.2	0.010	0.000	0.000	+0.010	0.000	0.000	46.0	46.0	0.311	100.0	3.6	"
	2	65.0	63.6	64.8	63.8	64.0	61.4	60.4	0.010	0.000	0.010	0.010	0.010	0.000	45.0	45.0	0.299	100.0	2.2	"
	3	65.0	63.4	64.8	63.8	63.8	61.4	60.2	0.010	0.010	0.010	0.010	0.000	0.010	44.0	44.0	0.288	100.0	2.6	"
	4	64.8	63.4	64.6	63.8	63.8	61.2	59.8	0.010	0.010	0.010	0.000	0.010	0.000	43.5	43.5	0.283	100.0	2.4	"
	5	64.8	63.2	64.4	63.4	63.4	61.0	59.8	0.010	0.015	0.010	0.010	0.010	0.005	45.0	43.0	0.275	92.0	2.2	"
	6	64.8	63.0	64.5	63.6	63.6	61.2	59.9	0.000	0.015	0.010	0.030	+0.045	0.015	47.0	47.0	0.323	100.0	3.0	W.
	7	64.8	63.0	64.6	63.8	63.9	62.0	60.8	0.000	0.010	0.015	0.010	0.005	0.010	52.2	50.0	0.361	93.0	3.5	"
	8	64.6	63.4	64.6	64.2	64.4	63.4	62.6	0.010	0.000	0.005	0.000	0.010	0.000	57.0	53.0	0.407	87.4	5.3	N.W.
	9	65.3	64.4	66.2	65.4	66.3	66.7	65.2	0.015	0.000	0.000	0.000	0.000	0.020	66.0	65.0	0.454	71.4	1.8	"
	10	67.2	66.0	68.8	68.5	67.5	68.6	69.2	0.000	0.010	0.000	0.010	0.010	+0.020	78.8	58.0	0.483	48.8	1.1	"
	11	68.4	68.2	70.8	69.6	70.2	70.6	72.2	0.007	0.000	0.000	0.010	0.000	0.000	82.0	57.0	0.460	42.2	0.9	N. E.
	12	70.2	69.6	72.2	71.0	71.8	72.1	74.4	0.008	0.020	0.020	0.010	0.015	0.000	78.0	54.0	0.427	44.5	1.3	N.
	1 P. M.	69.4	70.4	72.3	70.6	71.7	72.0	75.0	0.000	0.010	0.020	0.010	0.015	0.010	80.0	58.0	0.487	47.6	2.9	W.
	2	70.0	70.8	72.2	71.0	71.8	72.0	74.6	0.000	0.010	0.000	0.010	0.015	0.010	83.0	65.0	0.259	23.0	3.1	"
	3	70.0	70.6	71.4	70.7	71.0	71.2	73.4	0.000	0.010	0.020	0.015	0.015	0.015	79.0	55.0	0.431	43.4	2.8	S. W.
	4	70.4	69.9	70.5	70.3	70.5	70.0	71.8	0.005	0.010	0.010	0.010	0.010	0.015	73.0	57.0	0.459	56.6	3.3	E.
	5	69.7	69.0	69.4	69.4	69.4	68.2	69.2	0.005	0.010	0.010	0.015	0.010	0.020	67.0	57.0	0.472	71.5	4.2	"
	6	69.0	68.0	68.6	68.6	68.6	67.0	67.2	0.010	0.010	0.010	0.010	0.010	0.000	63.0	57.0	0.432	74.9	2.8	S. E.
Total.....		1667.5	1645.0	1676.4	1657.8	1661.8	1628.0	1625.2	0.160	0.210	0.205	0.200	0.130	0.175	1477.2	1280.5	9.200	1925.8	65.9	
Mean.....		66.6	65.7	67.0	66.3	66.4	65.1	65.0	0.0067	0.0087	0.0085	0.0083	0.0054	0.0073	59.1	51.1	0.366	76.9	2.7	
Means { Night.....		65.2	63.9	64.9	64.2	64.2	61.8	60.7	0.0083	0.0092	0.0080	0.0075	0.0012	0.0080	47.2	45.5	0.310	94.1	2.7	
Means { Day.....		68.1	67.6	69.1	68.4	68.7	68.4	69.3	0.0050	0.0083	0.0092	0.0092	0.0096	0.0066	70.9	56.7	0.423	59.7	2.7	

TABLE No. 3.—(*Continued.*)

Hourly Observations.—October 14–15, 1885.

Date.	Time.	Temperature at Surface, Fahr.							Evaporation, Inches.						Temp. of Air.	Dew Point.	Force of Vapor. Inches.	Relative Humidity. Per cent.	Wind.	
		Reservoir.	Tank No. 1.	Tank No. 2.	Tank No. 3.	Tank No. 4.	Tank No. 5.	Tank No. 7.	Tank No. 1.	Tank No. 2.	Tank No. 3.	Tank No. 4.	Tank No. 5.	Tank No. 7.					Miles per Hour.	Direction.
1885.																				
Oct. 14..	5 P.M..	56.0	57.4	57.0	56.4	56.6	56.8	58.0	.....	.....	.....	.....	.....	.....	55.0	52.5	0.390	90.1	....	S.
	6 ..	55.8	57.0	55.8	55.8	55.8	55.4	56.0	0.002	0.010	0.000	0.005	0.010	0.015	55.0	53.0	0.400	93.4	4.8	"
	7 ..	55.6	56.6	55.8	55.6	55.6	54.4	54.8	0.000	+0.010	0.005	0.000	+0.010	+0.005	52.0	50.0	0.361	93.0	3.7	"
	8 ..	55.6	56.0	55.4	55.3	55.3	53.6	53.8	0.008	0.010	+0.005	0.015	0.000	+0.010	50.0	47.0	0.321	89.1	3.4	S.W.
	9 ..	55.5	55.5	55.6	55.2	55.1	53.4	53.1	0.000	0.000	0.010	+0.005	0.010	0.025	49.0	47.0	0.322	92.6	3.1	"
	10 ..	55.5	55.0	55.4	54.9	54.8	53.0	52.5	0.000	0.005	0.010	0.000	0.005	0.005	49.0	45.0	0.297	85.3	6.5	"
	11 ..	55.5	54.7	55.3	54.9	54.7	52.9	52.5	0.000	0.015	0.000	0.010	0.010	0.005	48.5	46.0	0.303	88.8	5.5	"
	12 ..	55.5	54.5	55.3	54.7	54.7	52.7	52.2	0.000	+0.005	0.010	0.010	0.005	0.005	47.5	45.5	0.303	92.4	6.0	"
Oct. 15..	1 A.M..	55.4	54.6	55.2	54.8	54.6	52.8	52.0	0.015	+0.005	+0.010	0.000	+0.010	+0.005	47.0	45.0	0.297	92.3	6.3	"
	2 ..	55.4	54.4	55.2	54.6	54.6	52.6	51.6	0.015	0.005	0.010	0.000	0.000	0.000	45.5	44.0	0.293	96.0	5.7	"
	3 ..	55.4	54.2	55.2	54.6	54.6	52.6	51.8	0.000	0.015	0.000	0.005	0.010	0.015	46.0	46.0	0.311	100.0	5.0	"
	4 ..	55.4	54.2	55.2	54.6	54.4	52.4	51.8	0.000	0.000	0.000	0.010	0.000	0.000	47.0	46.0	0.310	96.1	7.1	"
	5 ..	55.2	54.2	55.0	54.6	54.4	52.8	52.2	0.010	0.000	0.010	0.000	0.000	0.000	47.0	46.0	0.310	96.1	6.8	"
	6 ..	55.2	54.2	55.0	54.6	54.4	52.6	52.2	0.000	0.020	0.000	0.005	0.000	0.005	48.0	47.0	0.322	96.2	5.6	"
	7 ..	55.2	54.1	55.0	54.8	54.6	53.2	52.7	+0.005	0.010	0.010	0.015	0.030	0.010	50.5	48.5	0.340	92.7	7.8	"
	8 ..	55.2	54.4	55.2	55.0	55.2	54.0	53.7	0.010	0.000	0.000	+0.005	0.000	+0.005	55.0	51.0	0.376	86.9	5.1	W.
	9 ..	55.3	54.8	55.8	55.4	56.0	55.4	55.7	0.005	0.010	0.000	0.000	0.000	0.020	57.0	48.0	0.336	72.2	9.7	"
	10 ..	55.6	55.2	57.0	56.8	57.6	57.0	57.5	0.005	0.005	0.010	0.020	0.010	0.000	61.0	52.0	0.383	71.3	8.1	"
	11 ..	56.0	56.2	58.4	57.8	59.0	58.6	59.2	0.000	0.000	0.000	0.010	0.010	0.000	63.5	52.0	0.392	69.4	8.3	N.W.
	12 ..	56.4	58.0	59.2	57.9	59.2	59.4	60.4	0.005	0.035	0.020	0.010	0.010	+0.005	65.8	50.0	0.358	56.3	7.5	"
	1 P.M..	56.2	57.3	57.8	57.2	58.0	58.0	59.4	0.005	+0.010	0.015	0.030	0.010	0.020	61.0	52.0	0.354	65.9	8.8	"
	2 ..	56.6	57.2	57.8	57.2	58.2	58.2	59.4	0.000	0.010	0.025	0.000	0.040	0.015	65.0	50.0	0.359	58.2	11.4	"
	3 ..	56.4	56.8	56.8	56.6	57.0	56.8	57.9	0.015	0.010	+0.010	+0.010	+0.030	0.000	60.0	48.0	0.338	65.3	9.8	"
	4 ..	56.4	56.5	56.4	56.4	56.4	55.8	56.4	0.005	0.020	0.010	0.015	0.040	0.010	57.5	49.5	0.357	75.4	10.1	W.
	5 ..	56.2	56.2	56.2	56.2	56.2	55.2	55.4	0.005	+0.010	0.000	0.005	+0.010	0.005	56.0	50.0	0.360	80.8	9.1	"
Total		1392.5	1389.2	1402.0	1391.9	1397.0	1369.6	1372.2	0.100	0.140	0.130	0.145	0.140	0.125	1338.8	1211.0	8.493	2095.8	165.2	
Mean		55.7	55.5	56.0	55.6	55.8	54.7	54.8	0.0042	0.0058	0.0054	0.0060	0.0058	0.0052	53.5	48.3	0.338	83.8	6.9	
Means { Night....		55.5	55.2	55.4	55.0	55.0	53.4	53.1	0.0042	0.0033	0.0033	0.0042	0.0025	0.0042	49.0	46.9	0.322	92.7	5.3	
{ Day.....		55.8	55.8	56.6	56.2	56.7	56.1	56.5	0.0042	0.0083	0.0075	0.0079	0.0091	0.0062	58.0	49.7	0.354	74.8	8.5	

TABLE No. 4.

Effects of Temperature on Evaporation.

1	2	3	4	5	6	7	8	9	10
Number of Experiment.	Date.	Duration.	No. of Pan.	Range of Temperature.	Mean Temp. Water Surface.	Max. Force of Vapor for Col. No. 6.	Av. Force of Vapor in the Air.	Difference ($V-v$).	Evaporation, Inches per Hour.
	1885.	Hours.		Fahr.	Fahr.	V.	v.		
1	April 18	7	1	36.0	138.4	5.621	0.350	5.271	0.1278
2	18	8	2	17.1	106.9	2.354	0.350	2.004	0.0340
3	18	8	3	7.2	71.9	0.782	0.350	0.432	0.0080
4	20	10	1	11.5	112.6	2.778	0.413	2.365	0.0442
5	20	10	2	7.2	88.0	1.323	0.413	0.910	0.0142
6	20	10	3	6.7	66.4	0.648	0.413	0 235	0.0036
7	20	6	4	12.1	64.0	0.596	0.433	0.163	0.0031
8	21	10	1	13 5	113.5	2.851	0.494	2.357	0.0412
9	21	10	2	5.4	89.2	1.375	0.494	0.881	0.0120
10	21	10	3	11.3	67.3	0.668	0.494	0.174	0.0035
11	21	10	4	15.8	66.7	0.655	0.494	0.161	0.0029
12	22	10	1	9.0	114.3	2.917	0.495	2.422	0.0449
13	22	10	2	16.2	92.1	1.505	0.495	1.010	0.0160
14	22	10	3	7.7	69.6	0.723	0.495	0.228	0.0032
15	22	10	4	8.1	68.5	0.696	0.495	0.201	0.0036
16	23	4	1	7.7	113.9	2.884	0.494	2.390	0.0400
17	23	4	2	3.6	89.8	1.401	0.494	0.907	0.0128
18	23	4	3	7.2	63.9	0.594	0.494	0.100	0.0034
19	23	4	4	9.9	63.0	0.576	0.494	0.082	0.0016
20	23	6	1	10.8	113.4	2.843	0.512	2.331	0.0423
21	23	6	2	3.6	87.6	1.306	0.512	0.794	0.0086
22	23	6	3	7.2	72.1	0.787	0.512	0.275	0.0036
23	23	6	4	8.5	73.0	0.811	0.512	0.299	0.0031
24	24	4	1	3.6	114.3	2.917	0.530	2.387	0.0397
25	24	4	2	5.0	92.1	1.505	0.530	0.975	0.0137
26	24	4	3	9.4	65.9	0.637	0.530	0.107	0.0025
27	24	4	4	4.7	64.9	0.615	0.530	0.085	0.0016
28	24	6	1	9.0	113.4	2 843	0.567	2.276	0.0373
29	24	6	2	2.7	89.4	1.383	0.567	0.816	0.0102
30	24	6	3	6.8	74.5	0.853	0.567	0.286	0.0042
31	24	6	4	6.3	76.3	0.906	0.567	0.339	0.0031
32	May 19	4	1	4.8	134.3	5.049	0.765	4.284	0.0759
33	19	4	2	5.4	119.9	3.416	0.765	2.651	0.0434
34	19	4	3	7.2	97.9	1.800	0.765	1.035	0.0156
35	20	9.5	1	18.5	132.7	4.841	0.499	4.342	0.0849
36	20	9.5	2	8.3	117.7	3.212	0.499	2.713	0.0468
37	20	9.5	3	8.6	98.0	1.805	0 499	1.306	0.0208
38	21	9.5	1	13.5	130.8	4.601	0.506	4.095	0.0787
39	21	9.5	2	7.2	118.1	3.248	0.506	2.742	0.0468
40	21	9.5	3	19.9	98.4	1.827	0.506	1.321	0.0224
41	22	9.5	1	6.3	135.0	5.143	0.557	4.586	0.0841
42	22	9.5	2	9.9	117.3	3.176	0.557	2.619	0.0425
43	22	9.5	3	9.0	98.0	1.805	0.557	1.248	0.0197
44	23	9	1	14.9	117.0	3.149	0.532	2.617	0.0549
45	23	9	2	6.7	134.7	5.103	0.532	4.571	0.0874
46	23	9	3	10.6	98.1	1.811	0.532	1.279	0.0192
47	25	5	1	9.0	117.7	3.212	0.642	2.570	0.0485
48	25	5	2	9.9	134.8	5.116	0.642	4.474	0.0832
49	25	5	3	5.7	96.5	1.725	0.642	1.083	0.0150
50	25	4.5	1	12.2	134.0	5.009	0.762	4.247	0.0911
51	25	4.5	2	8.1	118.5	3.285	0.762	2.523	0.0406
52	25	4.5	3	4.5	97.1	1.756	0.762	0.994	0.0142
53	26	5	1	11.7	128.9	4.372	0.550	3.822	0.0798
54	26	5	2	4.1	115.7	3.036	0.550	2.486	0.0397
55	26	5	3	7.4	96.5	1.725	0.550	1.175	0.0162
56	26	4.5	4	16.0	128.3	4.302	0.504	3.798	0.0719
57	26	4.5	2	9.9	114.8	2.959	0.504	2.455	0.0386

TABLE No. 4—(*Continued*).

Effects of Temperature on Evaporation.

1	2	3	4	5	6	7	8	9	10
Number of Experiment.	Date.	Duration.	No. of Pan.	Range of Temperature.	Mean Temp. Water Surface.	Max. Force of Vapor for Col. No 6.	Av. Force of Vapor in the Air.	Difference ($V-v$).	Evaporation. Inches per Hour.
	1885.	Hours.		Fahr.	Fahr.	V.	v.		
58	May 26	4 5	3	10.8	97.7	1.789	0.504	1.285	0.0169
59	27	9.5	1	11.5	99.2	1.872	0.474	1.398	0.0217
60	27	9.5	2	9.0	115.7	3.036	0.474	2.562	0.0406
61	27	9.5	3	11.7	132.4	4.801	0.474	4.327	0.0768
62	28	9.5	1	7.5	134.4	5.063	0.392	4.671	0.0893
63	28	9.5	2	10.8	117.2	3.167	0.392	2.775	0.0479
64	28	9.5	3	13.0	98.9	1.855	0.392	1.463	0.0230
65	29	9.5	1	7.7	125.3	3.966	0.477	3.489	0.0609
66	29	9.5	2	6.1	136.7	5.378	0.477	4.901	0.0888
67	29	9.5	3	14.7	102.1	2.013	0.477	1.566	0.0232
68	June 1	9.5	1	21.4	124.8	3.912	0.599	3.313	0.0628
69	1	9.5	2	14.2	135.7	5.239	0.599	4.640	0.0859
70	1	9.5	3	16.2	101.2	1.989	0.599	1.390	0.0203
71	2	9.5	1	9.2	102.1	2.043	0.385	1.658	0.0297
72	2	9.5	2	7.7	122.7	3.692	0 385	3.307	0.0572
73	2	9.5	3	9.0	136.2	5.308	0.385	4.923	0.0974
74	3	9.5	1	6.7	134.8	5.116	0.576	4.540	0.0897
75	3	9.5	2	3.6	135.5	5.211	0.576	4.635	0.0864
76	3	9.5	3	10.6	119.7	3.397	0.576	2.821	0.0501
77	4	9.5	1	11.7	135.2	5.170	0.674	4.496	0.0866
78	4	9.5	2	9.0	119.0	3.331	0.674	2.657	0.0470
79	4	9.5	3	16.2	102.2	2.049	0.674	1.375	0.0208
80	5	9.5	1	12.6	136.7	5.378	0.457	4.912	0.1050
81	5	9.5	2	9.0	119.4	3.369	0.457	2 912	0.0551
82	5	9.5	3	10.3	100.6	1.959	0.457	1.502	0.0248
83	6	9	1	6.8	137.5	5.491	0.480	5.011	0.1035
84	6	9	2	13.5	123.8	3.805	0.480	3.325	0.0614
85	6	9	3	14.4	102.6	2.080	0.480	1.600	0.0268
86	8	9.5	1	4.9	138.0	5.563	0.776	4.787	0.0929
87	8	9.5	2	16.7	125.9	4.031	0.776	3.255	0.0545
88	8	9.5	3	5.4	102.2	2.049	0.776	1.273	0.0182
89	10	7.5	1	9.2	121.6	3.581	0.455	3.126	0.0650
90	10	7.5	2	12.6	138.4	5.621	0.455	5.166	0.1028
91	10	7.5	3	14.4	102.8	2.087	0.455	1.632	0.0245
92	11	9.5	1	10.3	120.7	3.493	0.620	2.873	0.0555
93	11	9.5	2	14.4	138.9	5.694	0.620	5.074	0.1056
94	11	9.5	3	13.5	102.3	2.056	0.620	1.436	0.0199
95	12	9.5	1	14.9	124.0	3.826	0.704	3.122	0.0575
96	12	9.5	2	17.1	138.8	5.680	0.704	4.976	0.0953
97	12	9.5	3	14.6	103.5	2.150	0.704	1.446	0.0189
98	13	3	1	5.0	125.4	3.977	0.749	3.228	0.0575
99	13	3	2	8.6	156.5	8.852	0.749	8.103	0.1600
100	13	3	3	3.6	101.1	1.983	0.749	1.234	0.0167
101	13	3	1	7.5	122.2	3.652	0.781	2.871	0.0500
102	13	3	2	11.7	144.5	6.574	0.781	5.793	0.1054
103	13	3	3	9.9	104.5	2.195	0.781	1.414	0.0192
104	15	9.5	1	15.3	125.2	3.955	0.762	3.193	0.0546
105	15	9.5	2	10.4	146.9	6.984	0.762	6.222	0.1179
106	15	9.5	3	5.2	102.6	2.074	0.762	1.312	0.0167
107	16	2	1	4.5	102.9	2.093	1.015	1.078	0.0175
108	16	2	2	3.6	144.8	6.624	1.015	5.609	0.1050
109	16	2	3	5.2	100.4	1.942	1.015	0.927	0.0133
110	16	7.5	1	25.0	106.8	2.347	1.074	1.273	0.0188
111	16	7.5	2	11.7	150.0	7.547	1.074	6.473	0.1232
112	16	7.5	3	12.2	106.3	2.313	1.074	1.239	0.0153
113	18	1	1	3.9	105.2	2.240	0.588	1.652	0.0237
114	18	1	2	25.6	142.3	6.215	0.588	5.627	0.1137

TABLE No. 4—(*Continued*).

Effects of Temperature on Evaporation.

1	2	3	4	5	6	7	8	9.	10
Number of Experiment.	Date.	Duration.	No. of Pan.	Range of Temperture.	Mean Temp. Water Surface.	Max. Force of Vapor for Col. 6.	Av. Force of Vapor in the Air,	Difference, (V—v).	Evaporation Inches per Hour.
	1885.	Hours.		Fahr.	Fahr.	V.	v.		
115	June 18	1	3	2.7	103.5	2.131	0.588	1.543	0.0237
116	18	4	1	5.0	106.0	2.293	0.670	1.623	0.0281
117	18	4	2	5.4	158.4	9.267	0.670	8.597	0.1781
118	18	4	3	6.8	106.2	2.307	0 670	1.637	0.0244
119	18	4.5	1	4.5	104.8	2.214	0.739	1.475	0.0231
120	18	4.5	2	9.0	144.5	6.574	0.739	5.835	0.1103
121	18	4.5	3	12.6	106.5	2.327	0.739	1.588	0.0233
122	19	4	1	6.3	107.0	2.361	0.747	1.614	0.0259
123	19	4	2	9.9	152.2	7.969	0.747	7.222	0.1406
124	19	4	3	5.4	105.3	2.247	0.747	1.500	0.0222
125	24	2	2	9.0	106.3	2.313	0.544	1.769	0.0312
126	24	2	3	5.4	103.7	2.144	0.544	1.600	0.0218
127	24	3.5	1	9.0	138.8	5.680	0.623	5.057	0.1121
128	24	3.5	2	4.5	105.1	2.300	0.623	1.677	0.0253
129	24	3.5	3	8.1	104.6	2.201	0.623	1.578	0.0233
130	26	4	1	4.8	140.6	5.950	0.895	5.055	0.1038
131	26	4	2	12.6	108.0	2.431	0.895	1.536	0.0222
132	26	4	3	11.0	108.2	2.445	0.895	1.550	0.0240
133	26	5·5	1	13.1	133.7	4.970	0.912	4.058	0.0839
134	26	5.5	2	6.3	104.5	2.195	0.912	1.283	0.0175
135	26	5.5	3	5.7	103.7	2.145	0.912	1.233	0.0166
136	July 15	6.5	1	5.9	130.2	4.527	0.732	3.795	0.0677
137	15	6.5	2	4.1	129.9	4.491	0.732	3.759	0.0629
138	16	9.5	1	9 5	130.4	4.551	0.887	3.664	0.0696
139	16	9.5	2	8.6	130.8	4.601	0.887	3.714	0.0607
140	Aug. 7	8.5	1	5.4	129.2	4.408	0.680	3.728	0.0698
141	7	8.5	2	5.4	129.4	4.431	0.680	3.751	0.0623
142	8	8.0	1	12.6	128.9	4.372	0.752	3.620	0.0744
143	8	8.0	2	6.6	129.5	4.443	0.752	3.691	0.0656
144	Dec. 24	8.5	3	17.4	132.1	4.763	0.415	4.348	0.0992
145	26	6.5	3	16.7	131.2	4.637	0.193	4.444	0.1092
146	29	8.5	3	15.0	127.8	4.244	0.219	4.025	0.0963
147	30	8.5	3	10.8	135.3	5.184	0.460	4.724	0.1003
148	31	6.0	3	20.7	149.2	7.398	0.422	6.976	0.1715
	1886.								
149	Jan. 1	8.0	3	14.7	147.2	7.036	0.241	6.795	0.1602
150	2	8.0	3	19.8	149.2	7.398	0.333	7.065	0.1465
151	4	8.0	3	20.9	147.6	7.108	0.385	6.723	0.1456
152	5	8.0	3	8.8	149.7	7.491	0.496	6.995	0.1528
153	6	8.0	3	17.1	145.8	6.793	0.330	6.463	0.1486
154	7	8.0	3	31.1	159.6	9.538	0.117	9.421	0.2687

TABLE No. 5.

Effect of Wind on Evaporation.

Date.	Duration.	Mean Temp. Water.	Evaporation, Inches per Hour.	Max. Force of Vapor.	Force of Vapor in Air.	Diff. $V-v$.	$(V-v)^2$.	$.0012\ (V-v)^2$.	$.014\ (V-v)$.	$.014\ (V-v) + .0012\ (V-v)^2$	Evap. ÷ by preceding Col. Wind Factor.	Mean Wind. Miles per Hour.
1885.		Fahr.		V.	v.							
April 8	9.5	107.6	0.0740	2.403	0.386	2.017	4.0683	.00488	.02824	.03312	2.234	2.6
8	9.5	108.7	0.0698	2.481	0.386	2.095	4.3890	.00527	.02933	.03460	2.017	2.6
8	9.5	110.8	0.0764	2 638	0.386	2.252	5.0715	.00609	.03153	.03762	2.031	2.6
9	3.0	102.6	0.1379	2.074	0.103	1.971	3.8848	.00466	.02759	.03225	4.276	13.8
9	3.5	79.6	0.0539	1.010	0.103	0.907	0.8226	.00099	.01270	.01369	3.937	13.8
9	3.5	63.0	0.0346	0.576	0.103	0.473	0.2237	.00027	.00662	.00689	5.022	13.8
9	2.5	98.4	0.1169	1.827	0.113	1.714	2.9378	.00353	.02400	.02753	4.246	11.52
9	2.5	83.1	0.0660	1.131	0.113	1.018	1.0363	00124	.01425	01549	4.261	11.52
9	2.5	67.0	0.0374	0.662	0.113	0.549	0.3014	.00036	.00769	.00805	4.646	11.52
9	2.0	100.0	0.1175	1.918	0.098	1.820	3.3124	.00397	.02548	.02945	3.990	10.25
9	2.0	87.4	0.0656	1.298	0.098	1.200	1.4400	.00173	.01680	.01853	3.540	10.25
9	2.0	69.5	0.0393	0.721	0.098	0.623	0.3881	.00047	.00872	.00919	4.276	10.25
10	9.5	110.3	0.1086	2.600	0.139	2.461	6.0565	.00727	.03445	.04172	2.603	4.2
10	9.5	91.6	0.0578	1.436	0.139	1.297	1.6822	.00202	.01816	.02018	2.864	4.2
10	9.5	71.8	0.0320	0.779	0.139	0.640	0.4096	.00049	.00896	.00945	3.386	4.2
11	3.0	114.6	0.1032	2.942	0.130	2.812	7.9073	.00949	.03937	.04886	2.112	2.4
11	4.0	108.5	0.0965	2.467	0.117	2.350	5.5225	.00663	.03290	.03953	2.441	4.2
11	2.0	107.9	0.0998	2.424	0.118	2.306	5.3176	.00638	.03228	.03866	2.582	5.0
11	3.0	98.1	0.0602	1.811	0.130	1.681	2.8258	.00339	.02353	.02692	2.236	2.4
11	4.0	97 2	0.0621	1.762	0.117	1.645	2.7060	.00325	.02303	.02628	2.363	4.2
11	1.5	92.8	0.0598	1.538	0.118	1.420	2.0164	.00242	.01988	.02230	2.682	5.0
11	3.0	74.7	0.0250	0.859	0.130	0.729	0.5314	.00064	.01021	.01085	2.304	2.4
11	4.0	71.2	0.0303	0.763	0.117	0.646	0.4173	00050	.00905	.00955	3.173	4.2
11	2.0	71 6	0.0318	0.774	0.118	0.656	0.4303	.00052	.00919	.00971	3.275	5.0
13	10.0	114.0	0.0921	2.892	0.192	2.700	7.2900	.00875	.03780	.04655	1.978	2.3
13	10.0	89.4	0.0341	1.384	0.192	1.192	1.4209	.00171	.01669	.01840	1.853	2.3
13	10.0	61.7	0.0107	0.550	0.192	0.358	0.1282	.00015	.00501	.00516	2.074	2.3
13	2.0	41.9	0.0031	0.266	0.208	0.058	0.0034	.00000	.00081	.00081	3.827	1.0
14	10.0	111.9	0.1316	2.723	0.169	2.554	6.5229	.00783	.03576	.04359	3.019	8.0
14	10.0	89.4	0.0544	1.384	0.169	1.215	1.4762	.00177	.01701	.01878	2.897	8.0
14	10.0	61.0	0.0196	0.537	0.169	0.368	0.1354	.00016	.00515	.00531	3.691	8.0
15	8.0	113.4	0.0898	2.843	0.129	2.714	7.3658	.00884	.03800	.04684	1.917	2.1
15	10.0	89.6	0.0356	1.392	0.130	1.262	1.5926	.00191	.01767	.01958	1.818	2.2
15	10.0	61.5	0.0126	0.546	0.130	0.416	0.1731	.00021	.00582	.00603	2.090	2.2
16	10.0	110.1	0.1252	2.585	0.109	2.476	6.1306	.00736	.03466	.04202	2.980	8.6
16	10.0	87.6	0.0548	1.306	0.109	1.197	1.4328	.00172	.01676	.01848	2.965	8.6
16	10.0	59.4	0.0238	0.507	0.109	0.398	0.1584	.00019	.00557	.00576	4.132	8.6
17	4.0	110.5	0.1130	2.615	0.148	2.467	6.0861	.00730	.03454	.04184	2.700	7.2
17	4.0	88.7	0.0547	1.353	0.148	1.205	1.4520	.00174	.01687	.01861	2.939	7.2
17	4.0	59.5	0.0209	0.509	0.148	0.361	0.1303	.00016	.00505	.00521	4.012	7.2
17	5.0	111.5	0.1277	2.692	0.147	2.545	6.4770	.00777	.03563	.04340	2.943	9.3
17	5.0	88.5	0.0539	1.344	0.147	1.197	1.4328	.00172	.01676	.01848	2.917	9.3
17	5.0	59.6	0.0227	0.511	0.147	0.364	0.1325	.00016	.00510	.00526	4.315	9.3

TABLE No. 6.

Comparisons between Hourly Evaporations, Computed and Observed.

Date.		Temp. of Water.	V	v.	$V-v$.	$1+\frac{w}{2}$	Evaporation per hour. Computed. $\frac{(V-v)\left(1+\frac{w}{2}\right)}{60}$	Observed.
1885								
June 23...	5–6 P.M.	70.2	0.738	0.275	0.463	2.9	0.022	0.020
	6–7	70.0	0.733	0.270	0.463	2.8	0.021	0.011
	7–8	69.9	0.730	0.295	0.435	1.9	0.013	0.011
	8–9	69.7	0.725	0.310	0.415	1.6	0.011	0.013
	9–10	69.5	0.721	0.307	0.414	1.7	0.011	0.020
	10–11	69.3	0.716	0.294	0.422	2.2	0.015	0.020
	11–12	69.2	0.714	0.281	0.433	2.3	0.016	0.020
June 24...	12–1 A.M.	69.0	0.708	0.289	0.419	2.1	0.014	0.020
	1–2	68.8	0.704	0.304	0.400	2.0	0.013	0.020
	2–3	68.6	0.699	0.293	0.406	2.5	0.017	0.020
	3–4	68.3	0.692	0.253	0.439	3.1	0.022	0.022
	4–5	68.2	0.689	0.237	0.452	3.3	0.025	0.022
	5–6	68.1	0.687	0.257	0.430	3.6	0.025	0.021
	6–7	67.9	0.682	0.267	0.415	3.0	0.020	0.015
	7–8	67.8	0.680	0.275	0.405	3.7	0.025	0.015
	8–9	68.0	0.685	0.280	0.405	4.1	0.027	0.015
	9–10	68.2	0.689	0.286	0.403	4.2	0.028	0.015
	10–11	68.3	0.692	0.294	0.398	3.5	0.023	0.015
	11–12	68.6	0.699	0.295	0.404	4.4	0.029	0.010
	12–1 P.M.	69.0	0.708	0.303	0.405	3.9	0.026	0.018
	1–2	69.5	0.721	0.313	0.408	3.6	0.024	0.018
	2–3	70.0	0.733	0.325	0.408	3.2	0.021	0.019
	3–4	70.1	0.735	0.335	0.400	2.9	0.019	0.020
	4–5	70.0	0.733	0.377	0.356	2.6	0.015	0.020
July 8...	5–6 P.M.	82.6	1.114	0.840	0.274	1.2	0.005	0.002
	6–7	81.8	1.085	0.811	0.274	1.3	0.006	0.006
	7–8	80.9	1.054	0.724	0.330	1.5	0.008	0.004
	8–9	80.0	1.023	0.670	0.353	1.5	0.009	0.010
	9–10	79.2	0.997	0.647	0.350	1.7	0.010	0.010
	10–11	78.5	0.974	0.644	0.330	1.6	0.009	0.010
	11–12	78.0	0.958	0.630	0.328	1.6	0.009	0.010
July 9...	12–1 A.M.	77.6	0.946	0.612	0.334	1.8	0.010	0.010
	1–2	77.2	0.933	0.613	0.320	1.9	0.010	0.010
	2–3	76.9	0.924	0.612	0.312	1.9	0.010	0.015
	3–4	76.7	0.918	0.606	0.312	1.8	0.009	0.015
	4–5	76.5	0.912	0.617	0.295	1.9	0.009	0.009
	5–6	76.4	0.909	0.653	0.256	2.0	0.008	0.011
	6–7	76.3	0.906	0.695	0.211	2.1	0.007	0.010
	7–8	76.4	0.909	0.749	0.260	2.0	0.009	0.010
	8–9	77.4	0.939	0.807	0.132	1.9	0.004	0.010
	9–10	79.0	0.990	0.806	0.184	1.9	0.006	0.003
	10–11	81.0	1.057	0.799	0.258	2.1	0.009	0.010
	11–12	82.5	1.110	0.791	0.319	2.2	0.012	0.002
	12–1 P.M.	83.3	1.139	0.784	0.355	2.5	0.014	0.010
	1–2	83.5	1.146	0.793	0.353	3.1	0.018	0.015
	2–3	83.0	1.128	0.780	0.348	2.9	0.017	0.020
	3–4	82.4	1.106	0.776	0.330	2.4	0.013	0.010
	4–5	82.0	1.092	0.700	0.392	3.0	0.020	0.020
	5–6	80.5	1.040	0.601	0.439	3.0	0.022	0.000
	6–7	79.0	0.990	0.611	0.379	2.0	0.013	0.000
	7–8	78.6	0.977	0.648	0.329	1.8	0.010	0.010
	8–9	78.3	0.968	0.656	0.312	1.6	0.008	0.015
	9–10	78.2	0.964	0.661	0.303	1.7	0.008	0.010
	10–11	77.9	0.955	0.669	0.286	1.8	0.008	0.015
	11–12	77.7	0.949	0.677	0.272	2.1	0.009	0.010
July 10...	12–1 A.M.	77.5	0.943	0.668	0.275	1.4	0.006	0.005
	1–2	77.3	0.936	0.637	0.299	1.4	0.007	0.015
	2–3	77.1	0.930	0.622	0.308	1.8	0.009	0.005
	3–4	76.9	0.924	0.622	0.302	1.7	0.008	0.010
	4–5	76.7	0.918	0.633	0.285	2.0	0.009	0.005
	5–6	76.4	0.909	0.652	0.257	2.0	0.008	0.014

TABLE No. 6.—(*Continued.*)

Comparisons between Hourly Evaporations, Computed and Observed.

Date.		Temp. of Water.	V.	v.	$V-v$.	$1+\frac{w}{2}$	Evaporation per hour. Computed. $\frac{V-v)\left(1+\frac{w}{2}\right)}{60}$	Observed.
1885.								
July 10...	6-7 A.M.	76.4	0.909	0.670	0.239	2.0	0.008	0.006
	7-8	76.5	0.912	0.690	0.222	2.2	0.008	0.004
	8-9	76.7	0.918	0.793	0.125	2.9	0.006	0.011
	9-10	77.2	0.933	0.768	0.165	3.0	0.008	0.020
	10-11	77.4	0.939	0.631	0.308	3.8	0.019	0.010
	11-12	77.4	0.939	0.644	0.295	3.2	0.016	0.010
	12-1 P.M.	77.6	0.946	0.677	0.269	2.6	0.011	0.010
	1-2	78.5	0.974	0.698	0.276	2.7	0.012	0.000
	2-3	79.1	0.993	0.665	0.328	3.2	0.017	0.035
	3-4	79.1	0.993	0.593	0.400	2.8	0.019	0.010
	4-5	78.9	0.987	0.581	0.406	2.4	0.016	0.025
	5-6	78.5	0.974	0.596	0.378	2.2	0.014	0.012
	6-7	78.2	0.964	0.587	0.377	2.8	0.017	0.020
	7-8	77.8	0.952	0.565	0.387	2.2	0.014	0.013
	8-9	77.3	0.936	0.556	0.380	2.2	0.014	0.014
	9-10	77.1	0.930	0.549	0.381	2.3	0.014	0.006
	10-11	76.9	0.924	0.539	0.385	2.0	0.013	0.025
	11-12	76.6	0.915	0.523	0.392	2.1	0.013	0.010
July 11...	12-1 A.M.	76.4	0.909	0.513	0.396	1.6	0.010	0.010
	1-2	76.2	0.903	0.506	0.397	2.0	0.013	0.007
	2-3	76.0	0.897	0.510	0.387	2.2	0.014	0.018
	3-4	75.7	0.888	0.504	0.384	1.8	0.011	0.005
	4-5	75.5	0.882	0.497	0.385	2.0	0.013	0.010
	5-6	75.2	0.873	0.519	0.354	2.0	0.012	0.018
	6-7	75.2	0.873	0.543	0.330	2.3	0.012	0.012
	7-8	75.5	0.882	0.547	0.335	2.3	0.012	0.010
	8-9	75.7	0.888	0.543	0.345	2.2	0.012	0.010
	9-10	76.2	0.903	0.550	0.353	2.3	0.013	0.010
	10-11	77.1	0.930	0.562	0.368	1.8	0.011	0.010
	11-12	78.3	0.968	0.581	0.387	1.8	0.011	0.000
	12-1 P.M.	79.3	1.000	0.593	0.407	2.1	0.014	0.010
	1-2	80.0	1.023	0.595	0.428	2.1	0.015	0.010
	2-3	80.3	1.033	0.586	0.447	2.0	0.015	0.015
	3-4	80.0	1.023	0.542	0.481	2.0	0.016	0.010
	4-5	79.5	1.006	0.530	0.476	2.3	0.018	0.015

Summary of Table No 6.

Hourly Observations.

	Computed Evaporation.	Observed Evaporation.
June 23-24	*0.482 in.	0.420 in.
July 8-9	0.241 "	0.242 "
" 9-10	0.265 "	0.255 "
" 10-11	0.321 "	0.280 "
Daily Means.		
July .....28 days	7.08 "	6.34 "

* On June 23-24 there was a high wind. On July 8-9 the velocity of the wind was small.

TABLE No. 7.

Comparison between Daily Evaporations, Computed and Observed.

Date.	Mean Temp. of Water.	V.	v.	$V-v$.	$1+\frac{w}{2}$	Evaporation per hour. Computed. $\frac{(V-v)\left(1+\frac{w}{2}\right)}{60}$	Evaporation per hour. Observed.
1885.							
July 4...	75.1	0.870	0.546	0.324	1.6	0.008	0.005
5...	75.4	0.879	0.638	0.241	1.6	0.006	0.007
6...	74.3	0.847	0.627	0.220	1.6	0.006	0.007
7...	75.7	0.888	0.608	0.280	1.8	0.008	0.005
8...	78.8	0.983	0.681	0.302	1.8	0.009	0.005
9...	79.9	1.019	0.700	0.319	2.0	0.011	0.009
10...	77.8	0.951	0.650	0.301	2.3	0.011	0.012
11...	77.7	0.948	0.525	0.423	2.0	0.014	0.012
12...	76.8	0.921	0.420	0.501	1.9	0.016	0.013
13...	76.2	0.903	0.446	0.457	1.8	0.013	0.010
14...	74.2	0.844	0.569	0.275	1.7	0.008	0.012
15...	75.9	0.894	0.542	0.352	1.9	0.011	0.008
16...	77.8	0.951	0.629	0.322	1.7	0.009	0.009
17...	79.7	1.013	0.802	0.211	1.6	0.006	0.007
18...	80.2	1.029	0.685	0.344	2.1	0.012	0.008
19...	79.4	1.003	0.553	0.450	2.1	0.015	0.014
20...	80.1	1.026	0.593	0.433	1.8	0.013	0.010
21...	79.3	1.000	0.736	0.264	2.2	0.010	0.015
22...	80.1	1.026	0.689	0.337	2.1	0.011	0.009
23...	80.1	1.026	0.547	0.479	1.7	0.013	0.012
24...	79.0	0.990	0.664	0.326	1.9	0.010	0.012
25...	80.9	1.053	0.817	0.236	1.8	0.007	0.006
26...	80.7	1.046	0.677	0.369	2.0	0.012	0.010
27...	79.3	1.000	0.466	0.534	2.0	0.018	0.014
28...	78.3	0.964	0.517	0.447	1.6	0.012	0.012
29...	76.0	0.897	0.644	0.253	2.0	0.008	0.008
30...	76.2	0.903	0.569	0.334	2.0	0.011	0.007
31...	76.6	0.945	0.632	0.313	1.4	0.007	0.005
Total.....	.....	26.819	17.172	9.647	52.0	0.295	0.263
Mean.....	78.0	0.960	0.614	0.345	1.8	0.0104	0.0094

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THE CAUSE AND PREVENTION OF THE DECAY OF BUILDING STONE.

By THOMAS EGLESTON, Ph.D., M. Am. Soc. C. E.

READ JUNE 24TH, 1885.

WITH DISCUSSION.

In the years 1858–59, I had occasion to pass several months in the City of Rodez, the capital and also the cathedral town of the Department of Aveyron, in France. The cathedral was on the line of the Huguenot wars. It showed in every part the mistaken zeal of those religionists, much of whose energy was expended in destroying what was most beautiful. The main doors were a succession of diminishing arches lined with beautifully carved figures of saints in high relief, but every projecting piece that could be reached had been battered with a hammer, so that there was not a head, a leg, or an arm left on the hundreds of figures that formerly ornamented these doors. The cathedral foundations were laid in the eighth century. The building was finished in the last. It is constructed of red sandstone, very like the stone so much used in this city, and is the most prominent building in the vicinity. I had not passed it many times before I noticed that the stone of which it was built was subject to serious decay. It was not long before my attention was attracted to the fact that while the lower part of the church,

which was completed previous to the fifteenth or sixteenth century, had the mouldings and carvings which were left by the Huguenots perfectly sharp; all of the upper part, which was finished later, was almost a ruin. This was all the more remarkable, because the upper part was completed at a time when what might be called geometrical architecture was the fashion. There were geometrical staircases on every hand, staircases within staircases, lanterns supported on flying buttresses, and almost every other architectural puzzle that was in vogue in those days. It was not long before I noticed the fact that where the stone in any part of the building had a siliceous binding material, neither the mouldings nor the surface of the stone were decomposed; but in proportion as the siliceous binding material decreased in quantity, so also was the stone decomposed, until some parts of the church had actually fallen from decay, and others were in danger. Having occasion to pass the cathedral almost every day for four or five months during different years, I became greatly interested in the study of the decomposition that was taking place in the stone composing it, as also in all the other varieties used in the vicinity. Being obliged to return to America in the year 1860, I noticed the same process of decomposition going on in some of the brownstones of this city, and began almost at once to make some experiments with a view of arresting the decay, some of which were so successful that the building on which they were made had the progress of its decomposition almost entirely arrested, and it would have remained so for some years to come, if the front had not been taken down for alterations two years ago.

In the year 1878, I noticed that the stone of which Trinity Church, in this city, is built, showed serious signs of decay. In the year 1880 it became necessary to undertake a thorough investigation of the causes of this decay, in the hope of learning some means of checking it. The work was placed in my hands. As the examination could not but be a difficult one, I commenced it by making a careful study of all those parts of the church where the stone was decomposed. The fact became evident at once that in almost every place where decomposition had begun, it was immediately under a projecting piece which produced surfaces more or less horizontal. It was apparent at once that at least a part of the decay was due to a defect in the construction of the mouldings themselves, none of them being properly undercut, so that they do not shed rain as they should. In one or two instances imperfect stone was

used in the construction of the church, and in a very few places decomposition has been caused by the position occupied by the stone itself. These studies of the stone in place, and of its decomposition, lasted through several months. I examined the stone inside and outside of the church, as far as it was accessible, high up into the steeple, and became aware that there were used in its construction four different kinds of stone, and that the rate of decomposition was likely to be different in each.

After learning what these varieties of stone were, and the mode of decomposition of each, I selected for examination thirty specimens from all parts of the building, both inside and out, some of which were pieces apparently fresh, and others were scales of more or less thickness, which were easily separated from the stone. A careful physical, chemical and microscopical examination was made of all of these specimens. As the investigation was somewhat extended, and involved the complete review of the whole subject of the decay of building material, and as what has been supposed to be one of the most permanent building-stones of New York and other cities, is undergoing the same decay as other stones in this country, I obtained the permission of the corporation of Trinity Church to publish my results. I have thought that it would be of interest to present to this Society a short review of the whole subject of the decay of building-stone, as well as the investigation of the condition of this particular building. The matter is of all the greater interest at the present time, as not only some of the public buildings, but also monuments, which were designed to last for centuries, are, after only a very few years, showing serious signs of decay.

When we take into consideration what may be found in the air of cities, it is not at all surprising that stones which contain any soluble material should have this soluble portion dissolved in the course of time. The air of any large city may contain carbonic acid, nitric acid, muriatic acid, several different varieties of organic acids, ozone and ammonia. On making some experiments to ascertain the effect of solutions of carbonic acid dissolved in minute quantities in water, it was found that 1 428 parts of a saturated solution of carbonic acid in water were required to dissolve one part of carbonate of lime at zero Centigrade; at 10 degrees Centigrade, it required only 1 136 parts of acid. At a much higher temperature a considerably larger quantity of lime was dissolved. It was also found that dolomite was not so readily

soluble in solutions containing carbonic acid as carbonate of lime. One part of artificial carbonate of magnesia is soluble in 150 to 300 parts of carbonic acid. The mineral magnesite is soluble in 5 071 parts of pure water at 15 degrees Centigrade, with no carbonic acid in it. Artificial carbonate of magnesia, containing three equivalents of water, is soluble in 48 parts. It is also a well-known fact that concentrated solutions dissolve proportionately less than very dilute ones. Carbonic acid is found in the purest air to the extent of about $\frac{3}{100}$ of 1 per cent., and in the air of large cities to three times that amount. It is therefore not at all wonderful that this action of solution should take place in building stone. It is known that nitric acid is generated in small quantities by lightning, and that muriatic acid is frequently found, to the amount of from 1 to 1½ grains to the gallon of air, in localities situated near manufactories or near the sea. Organic acids are sometimes found in the air in considerable quantities; and recent researches* have proved that these organic acids will attack minerals which are completely insoluble in ordinary acids, so that it has been proposed to substitute them entirely for the mineral acids in geological work; this is, perhaps, one of the reasons why the silicates in rocks are so easily absorbed by the plants, and will probably account for the ease of decomposition of the minerals contained in the rocks which gelatinize with acids, and also for a considerable amount of the decomposition in the pyroxene and amphibole series.

Messrs. Spring and Roland have recently communicated to the Belgian Academy a series of observations made upon the amount of carbonic acid contained in the atmosphere during a year. They give the result of 266 determinations made in the City of Liege, Belgium; on one side of which there is an industrial, on the other an agricultural district. The average amount of carbonic acid obtained in 10 000 parts of air was 5.1258 parts by weight and 3.3526 parts by volume. These gentlemen remark that this is more than the amount contained in the air of Paris, which is 4.831 parts by weight and 3.168 by volume. The larger amount at Liege is owing not only to the large iron-works there, but also to the fact that the city is surrounded by coal mines. To this the authors attribute the greater heat of the city, as it is well known that a small quantity of carbonic acid in the air causes the absorption and prevents the radiation of heat. They also attribute the cold weather

* Annals New York Academy Science, Vol. I, p. 1.

of May to the diminution of the carbonic acid caused by the absorption of it by the growing leaves. Their observations show that a fall of snow will increase the amount to 3.761 by volume, and that in cloudy weather the amount was 3.571 parts, and that there was always a larger amount in winter than in summer. They also found that the quantity was diminished by high winds, but increased with a high barometer; all of which researches go to show that at the very time when the stone is most likely to be acted upon unfavorably—that is, in the winter—there is the greatest amount of carbonic acid in the air. In Liege there are some examples of the decomposition caused by the effect of gases as striking as any that can be seen anywhere in Europe.

The quantity of coal that is burned in the City of New York every year amounts to 4 500 000 tons. If we estimate that this coal contains, on an average, one-half of one per cent. of sulphur, which is an extremely low estimate, this would amount to about 35 pounds of ordinary sulphuric acid per ton of coal consumed, discharged into the air from the oxidation of the sulphur, and would amount in the course of a year to 78 750 tons of sulphuric acid. In this part of the country we burn anthracite, which gives off little else than carbonic acid, carbonic oxide and sulphur. But in regions where bituminous coal is used, ammoniacal constituents are given off as well, and these are corrosive. In order to ascertain how much sulphuric acid could be collected from the rainfall of the city, a funnel and bottle were placed outside the window of the Metallurgical Laboratory of the School of Mines.* The funnel had an opening of 50 square centimeters. It was left exposed during 41 days. At the end of that time it contained 65 cubic centimeters of water. This water was found to contain 4½ milligrams of sulphuric acid. The experiment was not made with a view to catch all the sulphuric acid, but to see if some could be caught. Very many of the days were bright, and the quantity of acid gas thrown into the air must therefore have been many times that amount, although the quantity is very large and sufficiently accounts for the rapid decay going on in the brownstone of that building. It has been estimated that the value of a London winter's smoke, including the carbon which is lost, as well as the other materials volatilized with it, amounts to $25 000 000.

It does not appear that ordinary salt contained in the sea-air, or even

* This experiment was made by Mr. J. B. Mackintosh.

a considerable amount of sea-spray, has any very deleterious effect upon stone-work, except in so far as it produces a certain amount of other alkaline substances by the action of the salt upon other bases, and in this way becomes, like all other dampness, an agent of decomposition. Almost the only effect of it observable on buildings is its attack on tin roofing, which requires a protection of paint near the sea, while in the interior of the country it will last for years without rusting. A very interesting paper, giving the results of observations made near the city on the quantity of chlorides contained in our rainfall in the year 1884, has been recently published.* It is of great interest in this connection as showing that rain water may be a fertilizing as well as a very destructive agent.

It may be said, as a general rule, that stones are less valuable as they are more porous, for the reason that they are more likely to absorb water containing the gases which attack the ingredients, and also because the water absorbed in freezing, by its expansion tends to disintegrate the stone. It has been said that the act of freezing is equivalent to the blow of a ten-ton hammer on every square inch of surface. Whether this be so or not, the continued expansion and contraction of a porous stone is quite sufficient to disintegrate it, and this disintegration will be all the greater as the stone contains more water. Stones that have already begun to decompose absorb a much larger quantity of water than those which are fresh from the quarry, independent of the quarry water which they contain, and hence the decay will be more rapid as it progresses. Professor Wigner, who examined the obelisk on the Thames embankment, found that the weathered surface of the obelisk absorbed six times the amount of water that was absorbed by the stone which had suffered no decomposition. This, of itself, though small in amount, would be sufficient, in a climate like ours, to produce serious disintegration in the stone.

The builders of the early centuries seem to have understood the injurious action of water, whether as rain, hail or snow, upon their buildings better than we do. Nothing is more striking than the shape of the lintels and sills of their great buildings, which are put in with a sharp incline downward. The architecture of these buildings was carefully studied, even in the minutest detail, and this is not at all strange, since these early masons and builders were a religious fraternity, who studied

* School of Mines Quarterly, Vol. VI, p. 35.

everything carefully, intending that their monuments, which are mostly churches, should be built to last for ages.

It is very interesting in the history of a country to trace the effects of the building material which its people are in the habit of using, upon their methods of construction. In this country we began with wood, because that was the cheapest material and the most easily obtained. The forms that were adapted to wood, our architects have carried into stone, which is entirely unsuited for them, and hence the constant recurrence of flat surfaces, which retain the moisture and precipitate decomposition, which otherwise might be very slow. It is true that the old Dutch settlers here constructed their roofs to some extent with reference to the great quantity of snow which is the usual accompaniment of the winters of this climate; but their successors have everywhere adopted flat surfaces. It is not generally supposed that these are more deleterious to the stone in countries where there is snow and ice, than rain is in a country where there is only rain, but this is the fact; for where snow is allowed to lodge, the water running through it will concentrate beneath on the surface of the stone, and even when the snow above is not melted, if there is any thawing at all, the snow will be constantly moist on the bottom against the stone. This moisture percolates through the stone. The decomposition under projecting window sills and on the lower side of balconies from this cause, can be noticed everywhere throughout our cities.

There is another cause for the disintegration of stone, which, while it is not very powerful, contributes its share in weakening it, and that is the efflorescence upon or the formation within the stone itself of more or less soluble salts, which are generally sulphates. These, by exuding from the surface, and crystallizing both within and outside of the stone, must of necessity cause a pressure toward the outside, and thus, by producing more or less of a separation in the grains of the stone, tend to disintegrate it. In the modern haste to finish things rapidly, and the anxiety to produce cheap materials, almost everything is done with a view to gain money or to save time, while thoroughness and durability are neglected. The lime of which the mortar is made is burned in direct contact with a refuse fuel, and this contains very frequently considerable quantities of iron pyrites, from which sulphates more or less acid are produced, which are retained in the lime, and as these sulphates are usually more or less soluble, they either effloresce from the mortar,

making it weak and causing it to dissolve out from the joints itself, or infiltrate through the stone and crystallize there, some of the substance coming to the outside as a white stain.

There is, independent of this cause—imperfect work in the manufacture of brick—the formation of the sulphates of alumina from the presence of pyrites in the clay. They exist in it much more frequently than is generally supposed. This would form an alkaline sulphate of alumina, containing either potash or soda, and tend to dissever or weaken the brick. Washing these efflorescences off with sulphuric acid, as is frequently done on brick buildings, or the cleaning of the surfaces of limestone in the same way, still further tends to increase the decomposition and consequent weakness, unless the stone or brick be immediately washed thoroughly with hot water, which, however, is never done. The use of acids to cleanse any stone or brick-work is objectionable. There are a number of substances which can be used for this purpose which produce no injurious effect on the brick or stone, and are more effectual, while being quite as cheap as any acid. In underground work the presence of any considerable amount of pyrites in clay should cause extra precaution to be taken with the structure. The brick-work of the first tunnel under the lake at Chicago was crushed in several places, and the tunnel shoved out of place in many more, by the decomposition of the pyrites in the clay, when the work was allowed to remain exposed to the air too long before filling the space between the brick-work and the clay.

The corroding effect of sand carried by the wind at high velocity has a very decided influence in producing the disintegration of the surfaces of building materials. This is evident on the surface of every building which is exposed to the dust of cities and swept by the prevailing winds. My attention was first called to it by being asked to study the reason of the defacement of the inscriptions on certain tombstones of historic interest some years ago, which seemed to be produced by no assignable cause. These tombs were placed just where they received the dust blown by the city winds, through an opening quite narrow, but where the action was constant whenever the winds were of any great velocity. To ascertain exactly what the effect of the power of sand might be when driven by wind, I undertook a series of experiments on the abrasive power of sand, with the sand blast. These were made upon ordinary stones, commencing at first with the softer varieties. I very soon

found that there was no stone of hardness sufficient to resist the power of the blast even for a few minutes. I then tried hard white cast-iron and hardened steel, but found that they had only a small resisting power, and wishing to ascertain exactly what the force of the blast was, in terms which would be readily understood, I commenced a series of experiments on the minerals which compose the scale of hardness. I very soon found that there was no use in experimenting on stones less hard than the topaz. The surface abrasion was so rapid that they were in a very short time reduced to powder, so that there was no opportunity of examining critically the effects of the blast. I very much regret that I did not have an opportunity of examining the effect of the sand blast in regard to the toughness of materials acted on, as well as hardness; but the time during which I was permitted to use the blast was very limited, and I have never had the opportunity of continuing my experiments. I however learned in the course of them, that on soft materials which were elastic, the effect of the blast was either reduced to zero or was very much diminished. It is well known to those using the sand blast that very hard substances may be entirely protected from the effect of the blast by using either a rubber coating or a film of some soft metal like tin, which, from its elasticity, will throw the grains off, while the harder surfaces will be abraded by them. This is no doubt the reason why soapstones and other varieties of very soft rocks, when they do not include within them minerals like pyrites, which, by their decomposition, cause them to disintegrate, have resisted atmospheric influences for very long periods.

I give below a table showing the results of these experiments on the minerals in the scale of hardness, giving the name of the mineral, the time that it was under abrasion, and the weight in grams of the quantity lost by abrasion. The specimens which were subjected to investigation were necessarily small, as I had no idea when I began of the power of the blast. They, however, show conclusively the principle upon which the curious abrasions of rocks over large areas found in the far West, which are the admiration of the geologist and the wonder of the tourist, are produced:

Mineral.	Time under the Blast.	Quantity lost, Grams.
Topaz (Goute d'Eau)	1 minute	1.9707
" pebble	1 "	2.1499
Emery from Chester, Mass	1 "	4.9532
Corundum from Delaware Co., Pa	½ "	1.1698
Black diamond	3 "	0.0372
Black diamond	5 "	0.0497
Black diamond	8 "	0.0869

The emery from Chester, Mass., is contained in a considerable quantity of menaccanite and magnetite. A hole was made through the center of the specimen almost immediately, leaving the corundum projecting, but all of its surface was acted upon, though at a different rate from that of the magnetite. The iron minerals were so much softer than the corundum, that they worked out before the corundum had an opportunity of being very much abraded. A conical hole was made in the topaz pebble, which in a few seconds longer would have penetrated it, and the pebble would have broken in two from the increase of the hole towards the sides. The corundum crystal had also a conical hole made in it, large enough to put the little finger through. The face of the black diamond exposed to the blast was originally rough, but became quite smooth at the end of the experiment. A microscopic examination of the surface of each of the specimens showed a surface ground exactly like the rolled surface of stones exposed to abrasion against harder substances in water. There was nothing peculiar about it, except that wherever there was a difference in the composition, there was a difference in the depth of the pitting which is so characteristic of abraded surfaces.

In order to ascertain what the direct application of these facts to buildings might be, I commenced a series of examinations on the composition of the dust of cities. I found it made up of organic material of various kinds and sizes; of very minute, but very sharp particles of iron, mixed occasionally with other metals; and of considerable quantities of clear and very sharp quartz, with some feldspar, together with a few other minerals, such as are found in the paving-stones and dirt of cities, ground to an impalpable powder. After a heavy rain, preceded by high winds, I was soon able to collect considerable quantities of sharp quartz sand, which could be easily studied with a microscope. On a March day we are often made aware how sharp

such sand sometimes is. When such dust is carried by high winds of a velocity of from 30 to 90 miles an hour, it abrades the surface of all the soft and, after a time, of some of the harder stones, which cannot resist the power of this dust, hurled against it at such high velocities. If the surfaces of some abraded stones are examined with a microscope, grains of a material of a nature quite foreign to those of the stone will be found adhering to it. This effect is much more prominent in cities than in the open country, as it is there aided by the city gases, but it takes place in the country as well. I have not unfrequently seen buildings in the open country whose abraded surfaces were due to this cause alone.

These experiments prove the fact, beyond doubt, that even the hardest substance may be abraded by a comparatively soft material hurled against it at a high velocity. I had intended, at the close of these experiments, had I been able to get the use of the sand-blast machine, to gradually reduce the hardness of the sand and increase the velocity of the blast until I should have used flour, so as in this way to study the action of the soft material contained in the city dust upon the stone. I am satisfied, from many hundreds of observations made on monuments and on the surfaces of buildings, both in this country and abroad, that some at least of the decomposition that is attributed to other causes is due to the action of the winds. There are many places where the falling out of the mortar between the stones, and the rounding of the corners at that particular point, can hardly be attributable to any other cause. Usually such stones as these, unless they are very soft, have the abraded surface quite as hard as the rest of the stone, while those which are disintegrated from the loss of any part of the constituents of the stone, whether they are superficial or produced from internal causes, are always easily rubbed into sand. There are many instances of this character in the sandstones used in some of the old buildings of Europe, the binding material of the grains of which has been entirely siliceous, the stones being worn and rounded in this way so as to produce a very curious effect upon the weather-beaten surfaces. Independent of the effect of the sand hurled by high winds, it must be taken into account, also, that during violent rains, when the wind is high, the pressure of the wind will force into the stone several percentages more moisture than it would under other circumstances. If buildings so exposed to the action of rain blown against it by the wind have the usual architectural defects of flat surfaces and mouldings not undercut, the disintegration of the stone composing

them must be very rapid in cold climates. If, in addition to this action of the wind, any part of the binding material is dissolved out by the rain, the decay of the stone will be very rapid, and will be produced usually without any symptom of flaking, because the surface will be worn away before the decomposition has gone far enough into the interior to cause the flaking to take place. The decay, therefore, will generally remain unnoticed.

In the selection of stones for building purposes, too little attention is given to their microscopical characters, and sometimes, when they are so examined, too much stress is laid on phenomena of little importance. It will not do to say that because a rock contains a mineral that has already commenced to decompose, as shown by the examination under the microscope, therefore this stone is valueless. I have, in my collection of microscopic slides, several sandstones, the feldspar in which has commenced to kaolinize, but in which the decay has been arrested. This decomposition undoubtedly took place in these sandstones, which are of triassic origin, previous to the degradation of the rocks which now compose them. When these were ground up, and their elements redistributed to form the sandstone, there seems to have been a cessation of the causes which produced the decomposition, which was arrested, and has not since, so far as we can see, advanced any further in the rock.

The characters which it is important to observe are, whether there are contained in the stone, minerals which are either already decomposed, or are likely to become so; whether these minerals contain water in cavities in considerable quantities; or whether, either by disintegration or by the looseness of the binding material, the stone contains so many interstices or fissures that it is likely to absorb large amounts of water, which may either attack certain of the constituents, causing them to swell, or may itself, under the influence of a severe climate, have sufficient power, in the form of ice, to disintegrate the stone. The examination of the stone in the quarry should be conducted as a whole, and not with reference to a particular part of it, for it not unfrequently happens that stones composed of exactly the same minerals have entirely different properties, as granite and gneiss, for example, and yet one of them may not be a proper stone for outside construction. The age of the stone, since its extraction from the quarry, may or may not be in its favor. Nearly all stones are weaker immediately after their extraction, while they hold the quarry water, than after they have lost it.

Most stones after long exposure, more especially if they have not been uniformly moist, absorb more water than when they are fresh, and are therefore more likely to disintegrate from frost than when they were younger, or than if they were kept uniformly moist. Certain rocks exposed to high heat or to severe cold, lose their power of resistance along irregular lines of weakness, and tend to disintegrate, and this effect may be produced by artificial heating as well as by climate. Stones, therefore, which endure exceedingly well in one climate may not stand in another, as witness the attempt to use in this city certain limestones and sandstones which had stood exceedingly well abroad. The particular place where the structure is to be erected, whether in the city or country, is to be considered. In the city there are noxious and corroding gases, coming either from fuels or manufactories; the dryness or dampness of the ground is to be considered, and whether the particular spot chosen is well ventilated or not; in the country, whether the air is humid or dry, or whether there are prevailing high winds carrying sand. All these, and many other circumstances, have great influence on the durability of building-stones, and should be carefully considered before expensive structures are undertaken.

Building-stones may be divided into three general classes: first, the different varieties of granite and granitic rocks; second, the marbles, which may have a coarse or granular structure, and may be either limestone or dolomite or serpentine; third, the sandstones, which may be composed of material having an organic, an argillaceous, a ferruginous, a calcareous, or a siliceous binding material. Slates are occasionally used in building, but not frequently. They are subject to peculiar forms of decomposition when they are used as roofing material, about which little need be said, because the decomposition which they would undergo in such very thin sheets would hardly take place when they are used in thick pieces in the construction of an ordinary building. Besides these stones, there are a few others which are sometimes used in the vicinity where they are found, such as various kinds of trap or basalt and serpentines; also steatites, and some other very soft rocks. Their use, however, is not common. Each of these stones is subject to its own particular kind of decay, which may be either chemical or mechanical.

Granite is made up of quartz, feldspar and mica, and is considered entirely impervious to moisture, and until the two great fires of Chicago

and Boston, was believed to be an almost indestructible rock. Recent investigations have shown that it contains within itself many elements of destruction. Of the minerals which compose it, quartz is the only one which is not liable to be represented by several species. While orthoclase is generally the principal feldspar of this rock, it may be replaced in part or in whole by microcline, oligoclase, labradorite or albite. The mica may be muscovite or biotite, and possibly other varieties. The accessory minerals which either accompany it, or in some cases replace almost altogether some one of the regular constituents, are amphibole, pyroxene, epidote, tourmaline, and in certain varieties of Swedish granites, achmite. Of the other minerals, it is estimated that nearly two-thirds of all the known mineral species are found in sienitic rocks. At least ten of these accompany, in more or less large quantities, most granites. These are garnet, titanite, zircon, apatite, magnetite, menaccanite, hematite, pyrite, pyrrhotite and rutile. The variety of the species of feldspar and mica, as well as the way they are put together in the stone, changes both its appearance and its physical qualities. As the quartz is the hardest of the minerals, it might be supposed that it would give its hardness to the stone. This mineral, as it occurs in the interstices between the feldspar, seems to have been formed last. It is everywhere more or less granular and brittle, so that while it is harder than the feldspars, it does not make the rock hard. Crystals which are themselves quite friable, may be separated from it by slight taps of a pointed tool. There is in the School of Mines' collection a beautiful mass of epidote crystals two or three inches long, from New Hampshire, which when it arrived was entirely embedded in quartz, and was separated from it in this way. The feldspars are the minerals which give both the character and the hardness to the rock. This is due almost entirely to the condition of the feldspars, and although the quantity contained in two specimens may be the same, the character of the rock may be entirely different. When the crystals are distinct, and present highly polished cleavage faces, the rock will be hard; when on the contrary, they are lamellar and loosely aggregated, the rock will be soft. Not only are the granites of different hardness, but they possess different rates of expansion under heat, which, as will be shown, is one of the principal reasons for their disintegration. The power of absorbing water is also quite different. The amount of water likely to be absorbed by a well dried granite is a little less than one per cent., but when it has

been exposed a very long time to a hot, dry climate, and has become slightly disintegrated, it will, as shown by experiments made on the London obelisk, absorb several times that amount. This water, and the different rates of expansion of its constituent minerals, is the reason why granite spalls in cases of buildings exposed during large conflagrations. Granites are also of different degrees of fusibility, depending on the quantity and the kind of feldspar contained in them; those containing albite are much more readily fusible than those containing orthoclase, all the more so if the albite is, as it often is, in thin lamellæ. The amount of mica present will also influence both the texture and the durability of the stone. If it is scattered through the rock, about evenly diffused, and not in too large quantities, the rock will be strong, if the feldspar crystals are of the proper character. If it is in bunches it will render the stone weak where the bunches occur. If distributed in directions which are parallel to each other, it may make the rock so weak as to give it a tendency to cleave in the direction of the mica planes.

The presence of hornblende minerals does not seem to affect the strength of granite rocks, except so far as, after very long periods, it is liable to certain kinds of decomposition. It does not generally occur in planes arranged in given directions, and is rather in long crystals of a more or less fibrous nature scattered through the rock. Its fracture is somewhat fibrous, so that it seems rather to tend to consolidate than to weaken the stone. The granites containing hornblende are amongst those which have longest resisted decay and disintegration. It replaces the mica forming the famous syenites which were so much esteemed as building materials by the ancients. When hornblende is replaced by pyroxene, the rock is not durable. Pyroxene is much more brittle and breaks with a much more granular fracture than the hornblende minerals. It does not tend to form fibrous masses, so that the rock is much more brittle than those containing the hornblende minerals. Some New England granites are liable to chip and break, owing to the presence of this mineral, which, whenever it is bunched, is liable to crack out in nodules, or when it is in considerable quantity, evenly distributed, to make the stone brittle as a whole. These two minerals exist together in certain granites which are then all the stronger as they contain less pyroxene. When the rock contains hornblende alone, it is usually very tough. The feldspar present in such cases is almost invariably ortho-

clase, which, as it is the soundest and most permanent of the feldspar family, makes the stone a very desirable one.

It is very generally believed that granite cannot decompose. The kaolinization of the feldspar goes on with exceeding slowness, and except under conditions very favorable to it, would not be likely to have much influence for many years. Not so, however, with the other minerals which compose it. The quartz is often full of microscopic bubbles, carrying liquids liable to freeze by cold or to be transformed into gas by heat, so as to produce a maximum of tension. The least space between the minerals would thus tend to become widened by the lapse of time. When the mica is biotite, the rock is more liable to decay on account of the ease with which this mineral decomposes. When it is present in large quantities, it makes the rock tender from the readiness with which it cleaves. When it is stratified it makes parallel lines of weakness along which the stone splits. The quartz contained in the rock is usually full of cavities, some of which are microscopic and others macroscopic, which may disintegrate the quartz, either by the expansion of the liquid by heat or cold, and thus render the rock itself more liable to absorb moisture than before. Independently of all this is the general change in the structure of all granites when exposed to very great variations of temperature, which cause minute fissures along the lines of least resistance, which are constantly increased in width and depth, causing the stone to become weakened and finally to disintegrate. This is most frequently seen in granites in which the triclinic feldspars occur, and is most prominent in them when the crystals are large. The rate of expansion and contraction being different in three directions, when the variations of temperature are very great, cause separations to take place along the lines of cleavage of the crystals, which is the line of least resistance, which very soon produces irregular lines of weakness. These are rarely apparent to the eye, and may have been developed to a considerable extent without the possibility of detection, except by a microscopic examination, which is very rarely made. Examples of this are to be seen in the obelisk of Luxor, the one on the Thames embankment, and the one in Central Park, which are disintegrating rapidly, and in a few score of years, if left exposed, will probably be beyond remedy.

The decay which takes place in the granites is either chemical or mechanical. If chemical, it is either the result of the very slow decom-

position of the feldspars and micas of which they are composed, or else of some mineral contained in the granite which decomposes easily, and by its swelling either causes the stone to flake, or by its decomposition to become porous and leave the stone free to be mechanically acted upon by frost and rain. If mechanical, it is the result of the weakening produced along the lines of least resistance by the continued expansion and contraction of the stone where it is exposed either to very great, but gradual changes of temperature, or to sudden ones often repeated. This causes the stone to disintegrate, and is a simple mechanical action without any chemical change. Such weakness has been developed in some granites from this cause, as to produce considerable chipping of the stone in the quarry. It frequently occurs in the granites of New England to such an extent, as to almost convert the exterior of the rock to sand, or to break it up into very small pieces, so that it can be easily removed without blasting. If, in addition to this cause of mechanical weakness, the rock should contain pyroxene, it would be safer to reject the stone. The power of the action of frost is much greater than is usually supposed. It takes a long time for frost to enter any considerable distance into the interior of a stone. When it has once entered, it takes a much longer time to thaw out. I have known of cases where granitic rocks which were quite warm on the outside, where they were exposed to the sun, froze solid, liquid cartridges introduced into the drill-hole to blast the rock. In this case there was the rock in front, which had expanded by the heat at one rate, the rock behind, which was expanded by the frost at a different rate, both forces acting at the same time, both tending to weaken the stone. Such effects do not act to any extent when the stone is in constructions, but it may have acted previous to its being placed there, and have seriously weakened it. Such disintegration takes a very long time; has not been observed to any great extent, so far as my knowledge goes, in the building materials of this country, except in the quarries; and is easily provided against by a careful selection of the stone. It is, however, very common in some of the out-crops of quarries, especially in those granitic rocks which contain a very large proportion of mica, which mineral, as it is very easily cleaved, is always a source of weakness; especially so when it occurs arranged in parallel planes, or contains substances likely to undergo a chemical change. In many instances granites have been discarded by our architects as building

material because they do not resist fire. It is, however, not fair to judge of the quality of a granite by its more or less great fusibility. Granites exposed to the air always contain moisture. All of them are fusible, and all will spall and crack under the influence of such intense blow-pipe heat as occurred in the great fires of both Boston and Chicago. No other building-stone would have resisted those fires any better, for the limestones would have been burned to quick-lime, as they did; and the sandstones would have disintegrated in the same way. There is, however, great choice to be had in the selection of granites, on account of their mineralogical constitution, and the composition of the minerals which they contain. The amount of decay of which they are susceptible is the least of all natural stones, except some of the sandstones which have a siliceous cement. Granite to be used as a building-stone should be of uniform grain, free from dark spots or aggregations of minerals in bunches. It is all the better where there are the fewest number of minerals, especially of the triclinic feldspars or larger mica plates, or pyroxene contained in it. It should especially be free from iron compounds, which are likely to oxidize. The decompositions of any kind, whether chemical, physical or mechanical, are very slow, and take place for the most part only in stones which a careful examination would have caused to be rejected from the outset. A good granite will last for ages, but no granite with very large or very irregular sized feldspar crystals, or minerals likely to become oxidized, will last. It may even be said of bricks that when they are improperly burned, or made of a poor quality of clay, they will exfoliate, fall to powder or even be dissolved, while some of the Roman brick-work has stood for two thousand years, and is still in good condition.

Gneiss is formed of the same constituents as granite, and is subject to the same causes of disintegration, only in a much higher degree, as the more or less of lamination, which is due to the arrangement of the mica, causes it to split easily. There is every possible gradation of rock, from a recognizable granite through gneiss to a mica slate, depending on the relative abundance of the different minerals. Owing to the presence of so large an amount of mica, and that it frequently in addition contains a considerable amount of pyrites and other sulphides, it is likely to be a perishable stone. This is seen frequently in the rock of New York Island and elsewhere, where the rock is so soft on the surface that it is frequently possible to remove it to a depth of

several feet with a pick and shovel. Generally, when hard stone is reached after the removal of such a surface, the rock is worthless for several feet below, and will go on disintegrating if put into foundations or structures of any kind. I have seen slabs of gneiss 4 feet long by a foot thick, in retaining walls, so thoroughly disintegrated by the decomposition of the pyrites it contained, that it could be picked to pieces with the nail. These kinds of decomposition are constantly seen in the repairs to the foundations of old houses and sometimes in structures, but generally as such stone is buried it attracts but little attention. In retaining walls, whole sections built in the upper part of this city have become so weak in less than 20 years, that they have had to be rebuilt. It is also liable to exfoliation when set in the structure in such a way that the mica planes are subject to the action of heat. Occasionally, when the plane of the stone is at right angles to the quarry-bed, the quartz, or feldspar, when embedded in mica so that it is on all sides of it, will chip out. Generally, when properly used, if the stone has been carefully selected, it is a durable building material.

It is not generally known that rocks which are hard, and subject to almost no decomposition in one climate, may be thoroughly decomposed to great depth in another. Such a decomposition seems to be going on in the gneiss of New York Island. The water taken from the artesian wells of this city, and of the vicinity, often contain from 12 to 20 grains to the gallon of mineral matter in solution, and some of these, which have been sunk to the depth of 700 feet and over, contain from 6 to 13 grains to the gallon, of carbonate of soda, showing that the rock is undergoing decomposition at great depth as well as at the surface. It has generally been supposed that the brackishness of our artesian-well water was owing to the fact that the dip of the strata is such as to bring towards the center of the island, from both sides, the salt water of both of the rivers, but this could not explain, even if it was true, for such depths the presence of such large quantities of carbonate of soda. I have seen gneiss in North Carolina so thoroughly decomposed over a large area, and to a great depth, that it was soft like clay. In the vicinity of Van Tyne's Station, on the Richmond and Danville Railroad, there is an outcrop of a gneiss rock so decomposed that, while preserving to the eye alone all the characteristics of an unaltered rock, it can be made into balls like clay. This decomposition has been traced to a depth of 250 feet. In the same neighborhood is a trap-dike, over 60 feet wide, so

thoroughly decomposed that it can be shoveled up like dirt, with no indication that it ever was a rock, except that here and there, there are boulders 10 or 12 inches in diameter with an outside crust like the dirt, but a little harder, but having the unaltered rock in the center. I traced this dike for half a mile, and found it everywhere in the same condition. The railroad cuts through it in one place where the sides of the cut are over 50 feet high, showing the rock thoroughly decomposed from top to bottom. Such decomposition is quite common in modern volcanic rocks, and the soils which they furnish are much sought for by the wine growers.

Mica slate is composed of quartz and mica. It is of necessity laminated, and contains a large number of minerals included within it. It is fusible, and not very suitable for structures above ground, nor hardly for those below. The mica is generally biotite. It frequently is so rotten, from the action of decomposing pyrites, and from the decomposition of the mica, that it is unfit for anything but gravel. Such material, when thoroughly rotted, makes good roads and hard walks. It is sometimes used in buildings, but not often above ground. Its decay is not very rapid, but is quite sure in time, if the mica predominates, as it usually does.

Under the name of trap, several varieties of stone are included. As they cannot usually be got in large pieces, on account of their brittleness, they are used only occasionally for buildings, when they do not have to be carried any very great distance. They are composed mostly of a triclinic feldspar, which is often labradorite with pyroxene, peridot, magnetite, menaccanite, sometimes apatite, and a mica which is generally biotite. They are almost always accompanied by some form of chlorite, which is usually a product of decomposition. They are often full of small cavities which are lined with chalcedony and the zeolitic minerals. The decomposition seems to be caused by the solution of certain parts of the rock and a greater or less precipitation of the elements dissolved in the stone itself. The rock is usually tender and brittle while the quarry water is in it, and quite tough afterwards. Its decomposition is exceedingly slow. No great buildings have been made of it, on account of the impossibility of getting it in large pieces.

Serpentine is a hydrated silicate of magnesia of variable composition, and associated with a number of minerals of the same general composition. It is also a product of decomposition of other minerals. It is a

tough but soft stone, and may be in all conditions from roughly lamellar to almost granular. It is associated with chromite and magnetite, and frequently contains considerable quantities of calcite, and with certain fibrous minerals, which are sometimes a variety of the rock itself, and sometimes fibrous varieties of the amphibole series. When it is contained in calcite it is often used as an ornamental stone. Not unfrequently it is associated with the variety of steatite known as soapstone, when it becomes a serious impediment to the use of the steatite. Both stones have been used for building, although they are so soft as to be unsuitable for large structures. They have stood in some places where they have been used for 150 years; in others they have commenced to decompose in a much shorter time. This is owing to the variable nature of the rock, which is rarely ever homogeneous, either in composition or structure. When they are quite pure, both steatite and serpentine, though so very soft, are practically indestructible rocks. They are not generally, however, suited for use in large cities, on account of the considerable quantities of carbonates they contain, which are easily acted upon, and cause the stone both to lighten in color and to disintegrate on account of them. They can generally only be had in small pieces, which is objectionable in a building stone.

Under the name of porphyry are included a very large number of stones which have a compact, generally dark-colored base, with crystals either of feldspar or of quartz of a different color showing in them. These are generally either quartz or some kind of feldspar, or both. They usually occur in dikes. The stone is very hard and tough, and generally can only be had in small pieces. It has many different varieties of color, both of base and crystal, and is a very beautiful stone. It was very much sought for by the ancients, and was extensively used, both for construction and ornament. None of these stones used in their buildings show any trace of decomposition, and those found in the ancient ruins show only a slight diminution of the polish, which, where it was made very high, seems almost as indestructible as the stone itself. In places, however, it is quite frequently decomposed. I have seen considerable quantities of it decomposed to a clay, looking exactly like the unaltered rock, even to the colors of the crystals, with every ingredient, except the quartz, turned into a plastic clay, so soft that it could be easily moulded in the hand. This decomposition has, however, so far as I know, only been found *in situ*. The same kind of decomposition takes

place in the conglomerate rocks of Lake Superior, which are porphrytic, when all the constituents of the rock, except the quartz, are sometimes transformed into a soft clay. The entire replacement of the base of the rock by native copper is quite common, both in the conglomerate and amygdaloid rocks of that region.

Slates are little used in construction, both from the difficulty of getting out large blocks, on account of the ease with which they cleave, and also because of the unattractive color which most of them possess. They are sometimes used for building in the vicinity of large quarries, only those pieces, however, being used which do not readily cleave. They must always be placed in their quarry-bed. When placed in a vertical position they are very apt to laminate, but in the quarry-bed they have stood for hundreds of years. Some varieties are subject to a superficial decomposition, which changes the color to an unpleasant yellowish-gray, but it is very slow. When the slate contains pyrites its use must be avoided. Slates cannot be carried far as they are not much esteemed, but they are a durable stone when of good quality, and only objectionable on account of their color. They are used chiefly for roofing purposes, but are being gradually superseded of late years on account of their weight, it being more expensive to build a roof strong enough to support slate than one for a lighter roofing material. In the older parts of the city, where the Dutch traditions were still in force, the roofs were almost invariably made of slate and tile, and placed at an angle of 45 degrees, so as to prevent the accumulation of snow upon them. Tile having been found altogether unsuited to this climate, was abandoned entirely; but slate still continued popular until tin and other materials began to supersede it, as they are now doing to a great extent. It is not ordinarily subject to decomposition, and when this does take place in it, it is usually attributed to the presence of pyrites. I have, however, within a year, seen, on the roof of a house in Massachusetts, rather thick roofing slates, entirely free from pyrites, which were placed there twenty years ago, so decomposed that they will not bear the least pressure, and are broken into small pieces by the force of the wind. This decay is accompanied by a change of color; originally bluish-black, it changes almost to brown. After a little while, such slates will not only be no protection to the roof, but their presence will be an absolute detriment. This form of decay, however, is not found in slates of good quality, and is more of a lithological curiosity than a real danger to be guarded against.

Slate was formerly much used for ornamental purposes, and where that of good quality was selected it answered perfectly well, as it is capable of receiving very high polish. Owing, however, to the difficulty of securing a slate which was compact and hard, this use of them seems to have been abandoned. They are, however, still extensively used to make enameled surfaces for interior decoration. The old graveyards of New England contain many tombstones of slate dating back nearly to the close of the seventeenth century. Most of the slate headstones in Trinity churchyard are to all appearances entirely unaffected, and seem to be as strong and perfect as on the day they were placed there. Two of these were erected in 1691 and 1692, on the north side of the church, and were cut on both sides. One of them, that of 1691, shows no sign of deterioration, except an occasional spalling of very small pieces; the inscription is quite sharp. The other is very much broken on the lines of pseudo-cleavages, produced by pressure; but the surfaces of fracture, though produced many years ago, are quite fresh. The faces of both these stones are somewhat gray from alteration.

Of the different varieties of marble, those which are granular are the ones which are generally most easily attacked, and of the limestones and dolomites, the former seem to be most readily acted on, while those marbles which are composed of a mixture of limestone and dolomite, are very easily affected by the weather, the limestone going first and leaving the dolomite. Most of this weathering takes place on buildings in the country, or standing by themselves, by the decomposition of the minerals contained in the interior, which can easily be prevented by proper selection of the stone. Where the buildings, however, are in a confined space, especially in large cities, the action of the city gases is such as to attack the limestone, leaving the less easily affected dolomite altogether uninfluenced at first, and afterwards, according as there is more or less of lime present in it, causing it to crumble, or leaving a very rough surface. There are a number of notable examples of this decomposition in some of what were once the most beautiful tombs in our city churchyards, which have literally fallen into sand by the solution of the lime by the city gases. The commencement of this action may be seen on the monument to Alexander Hamilton in Trinity churchyard, and on the Emmet monument in St. Paul's. The same action is frequently seen in the dolomite quarries, as at Lee, Mass., where the limestone is dissolved out, leaving the dolomite as a sand with crystals of tremolite lying loosely in it.

The churchyards of the country also are full of stones undergoing this kind of decay; which, however, progresses much more slowly there than in the city. One of the most remarkable instances of decay of stone can be seen in the southern division of Trinity churchyard, near Broadway, about half way between the church and Rector streets, in the shape of a square marble monument with an inclined top now about four feet high. Originally this was twelve feet high, supported on polished columns, with an open space underneath, in the center of which was an urn. This monument was erected in the year 1820 to the memory of Grace Lyde. It was made of highly polished marble, and when it was put up, was one of the most beautiful and graceful monuments ever erected in any of our city churchyards. In the year 1860, the name on the monument had already become illegible. About five years ago it was in danger of falling, and an order was given by the church authorities to repair it. It was found, however, that the stone was so badly decomposed that it would not hold together under the pressure of its own weight, so that the monument could not be repaired. It had to be taken down. All of it that could be used was put up in its present shape. The decay has still further progressed since then. The stone is so soft that it easily crumbles between the fingers, and it is rapidly falling into sand. The inscription has entirely disappeared, and in a few years longer nothing will be left of it but sand. The Capitol, at Frankfort, Ky., was built in 1837 of a very fine-grained limestone, with some excess of carbonate of magnesia. This has become acted on, so that the building is completely coated with what appears to be a very fine wash, which is very adherent, but can be easily scraped off with a knife. It consists of carbonate of lime. The interior of the stone has suffered no decay.

As a general rule when a limestone contains much pyrites it should be discarded, but it does not always follow as a necessary consequence that the presence of pyrites in stone is of necessity a disadvantage. As a general rule the presence of marcasite is. Of the ordinary pyrites some varieties do not decompose, while others do; the presence of such varieties as decompose may disfigure the stone, if in small quantities only, or may cause it to swell and disintegrate if in large quantities. In compact stones its presence has but little influence; in porous ones it is generally objectionable. But no absolute rule should be laid down, for, while as a general thing it is to be avoided, it may be harmless. In gen-

eral it may be said that the presence of much pyrites makes the stone unfit for use in the exterior of buildings. It is often a matter of surprise that some limestones do not stand here, either in houses or in graveyard monuments, for any great length of time, while they have stood for thousands of years both in Italy and in Greece. This is, however, very easily explained, from the fact that in these countries in the situations where they have stood, the air is comparatively dry, and also does not contain so much, if any, of the injurious gases which affect our stones. In looking over our churchyards—Trinity, St. Paul's, St. John's, and Trinity cemetery—we find that the effect of weathering upon the marble is very curiously developed. If the stone is placed vertically, according as it is more or less compact, or is composed entirely of carbonate of lime, or partly of lime and dolomite, the polish on the stone will be very much deteriorated in the course of ten or fifteen years, and may, on certain stones, sometimes be entirely gone in less than that time.

There are many stones in Trinity and St. Paul's churchyards, placed there within the century, where the inscriptions have been entirely obliterated, leaving in their place a very rough surface, which scarcely shows any trace of the stone ever having been worked. In Trinity cemetery, at One Hundred and Fifty-sixth street and North River, where the air is much purer than it is in the city, some of the marble headstones have become so rotten after twenty years' exposure, that they will not bear their own weight, and crumble from the least friction, even of the hand. As a general rule the finer the texture and the closer the crystals are arranged in the stone, the less this disintegration has taken place. The monument erected in 1814 to the Sieur Rochefontaine, who commanded the French forces during the Revolution, was so far decomposed, that in the year 1885 the inscription was recut by order of the Corporation of Trinity Church. The monument not far from it, erected to G. F. Cook, the famous actor, by Edmund Kean, in 1821, was repaired by Charles Kean in 1846, and again by E. A. Sothern in 1874. Except on the south side, the inscriptions are now very much defaced. It was necessary to recut the inscription on the monument to Alexander Hamilton in Trinity churchyard, in 1885. The monument to Alexander Bradford, New York's first printer, erected in the year 1752, was so far defaced and crumbled, that in the year 1868 the Corporation put up a *facsimile* of the original stone. This is so far acted on already that sand

can be brushed off of its surface with the hand. The inscription on the altar tomb near that of Alexander Hamilton, in Trinity churchyard, is so far defaced, from the solution of the stone, that only a slight depression, where the lettering once was, can be distinguished on the surface of the stone. As the result of the examination of the New York City cemeteries, I am confirmed in the opinion that, in general, limestone, whatever its character, is entirely unsuited in this climate for the construction, in cities, of monuments which are to be exposed to the air. One of the most remarkable destructions of this kind which has ever come within my observation is that of the cathedral at Douai, in France; the whole of the outside coating of Caen stone of this church is gone, leaving nothing but the filling of brick and rubble to support the interior of the church. It is said that the whole of the outside of Westminster Abbey has already been replaced twice, and will soon have to be replaced a third time. The exterior of Cologne Cathedral was hardly finished before they commenced to repair it. Notre Dame, and the Tour St. Jaques, in Paris, require constant attention and repair.

The rate of disintegration in such stones used for buildings can be very much lessened by filling the pores of the stone where decay has already commenced, or previous to its being put into the building, with some substance like oil, paraffine, or sulphur. In the case of the experiments that have been tried upon the Houses of Parliament, it has been found that sulphur in solution has answered better than any of the other substances used as a remedy against this decomposition. It has also been found that the filling of the pores of that stone is generally useless if it has been done on the outside only. I saw several cases where the pores of the surface only of the stones, having been filled with sulphur, had retained their surfaces during twenty years of exposure, and were only just beginning to exfoliate. Where the remedy has been applied to the six sides of the stone previous to its being put into the structure, it seems to have been effective, such stones, after ten or fifteen years of exposure, showing no signs of decay.

Almost everything has been tried on the Houses of Parliament, but nothing as yet has been found to be successful. This is owing partly to the fact that a large proportion of the stone was unfit to put into any building under any conditions. The Commission which selected the quarry from which the stone should be taken was discharged when their

report was made, and no one was responsible for the stone selected after this quarry was found to contain an inadequate supply; and when it failed, stone was obtained almost anywhere that it could be had. The destruction has been so rapid, and the decomposition of their highly ornamented surfaces has extended so far, that in the case of finials and the small pinnacles which they surmount, they are now replaced by cast-iron painted the color of the stone.

From want of care in its selection, I have seen the *calcaire grossière* of Paris decompose so rapidly, that the stones had to be removed after a few years. Up to 1860 there were on the side of the Louvre next the Seine, between the passages that enter the Place du Carousel next the Tuileries, large stones which had fallen entirely into sand to a depth of over 6 inches, and the remaining portion was so soft that it could be picked to pieces with the finger-nail. This same decomposition took place also in certain sandstones with a calcareous binding material, which was much used in Paris at this time. I have often gathered fossils in the sands of the quarries from which both these kinds of stone were taken, certain beds of them on the outskirts of Paris being the favorite resort of fossil hunters. In this case there was both the original want of consolidation of the stone and subsequent decay to make it weak.

The silicates of soda and potash with which the surface of the Louvre in Paris was washed in 1858, seems to have been quite effectual. In this case a silicate of lime was formed, which has protected the surface from further action of the weather, but on the Houses of Parliament, owing to the bad quality and the extremely soft and porous nature of the stone, which required that the pores should be filled at the same time that the surface was indurated, it does not appear to have been successful.

Some years ago attempts were made to introduce Caen stone into this country, as it had proved so satisfactory in many buildings in England and France. A number of houses of this stone were erected both in New York and Brooklyn. About the same time the interior of Trinity Chapel on Twenty-fifth and Twenty-sixth streets was lined with this stone. In less than ten years the Caen stone used on the outside of buildings in Tenth street, between Fifth and Sixth avenues, began to exfoliate, and the fine carving crumbled to pieces before anything could be done to preserve it. The rest of the front of some of these buildings

has been preserved till this time only by keeping it constantly and carefully painted. To be effectual, this paint must be renewed every four or five years. The interior of Trinity Chapel, however, shows no trace of decomposition of any kind. The stone is a little clouded with dirt, but otherwise is apparently as sound as the day it was erected, showing that Caen stone is perfectly suitable for interior decoration when kept dry. Soft stones of this character can only be used in outside work in large cities by being kept constantly coated with paint.

It is not an uncommon thing where the dolomite and limestone are mixed together, in slabs that have been highly polished, to have the limestone filling between the crystals eaten out by the gases when they are placed in confined places in cities, which leave the dolomite crystals projecting, so that the surface looks as if it never had been polished. An excellent example of the commencement of such decay can be seen in the altar tombstones near the south entrance to Trinity Church, and in the Emmet monument in St. Paul's churchyard.

An extremely curious phenomenon sometimes takes place from the elasticity of limestones, which seems to threaten the immediate destruction of the stone, but which it may resist for a very long time. It is not confined entirely to limestones, but occurs in sandstones as well. This is the bulging of the stone owing to heat applied entirely on one side. From the constant expansion of the surface the crystals seem to assume a certain degree of mobility among themselves, so that the stone bends outward if placed in a vertical position, or sags, if there is opportunity for it, when placed horizontally. This phenomenon has been noticed in some of the public buildings in Europe, but has not attracted much attention here. Having occasion many years ago to examine into the cause of a smoking chimney, I found the opening at the top almost entirely closed by the sagging of the cap, which was a piece of dolomite 3 feet 6 inches square and 2 inches thick. I had it turned over with the bulged side up. In the course of another six months it had commenced to bend in the other direction. The next year it had to be turned over again, and after two or three turnings it finally broke. The heat of the fires on the under side had produced such a separation between the crystals as to cause their movement, and the successive bendings had weakened the stone so that it no longer had sufficient resistance to bear the strain of bending. In buildings the danger of bulging is

only that of throwing the stone out, as the expansion is on one side only, and as it can never occur except when the stone is used in thin slabs for facings, can always be provided against by the way in which the stone is fastened into the wall behind it. This same phenomena is often seen in altar tombs where the slab is not sufficiently supported in the center. It is most common in the coarse granular limestones, or those composed of mixtures of calcite and dolomite. Some such tombs can be seen both in Trinity and St. Paul's churchyards, which are so hollow in the center, that they hold sufficient water for the birds to bathe in. On most of such stones the inscription has been entirely obliterated. I have sometimes seen sandstones which had laminated in thick layers, from the solution of their binding material, curl away, by the heat of the sun, several inches from the stone behind them, in sheets over eighteen inches wide, and keep bending until they could no longer support their own weight.

Certain conglomerates, which are very hard when extracted from the quarry, undergo a more or less rapid decomposition when exposed to the air. Such conglomerates as these, composed mostly of quartz or limestone grains cemented together by an argillaceous material, are quite frequent in the coal formation, and are, of course, utterly unsuited for building material. There are, however, other limestone conglomerates, notably some of those breccia which are used in the public buildings of Washington, where the disintegration, though much slower, is none the less effective. The beautiful colonnade of the Treasury Department on Fifteenth street, in Washington, is made of Potomac marble, which is such a material as this. Some years before the war, the disintegration of this stone had progressed so far, that the complete destruction of the colonnade was threatened, so that it became necessary to prevent its extending further. It was coated with paint, and has been carefully protected in this way ever since. It is not generally known that the front of the old Capitol building and also of the White House, which are limestones, commenced to disintegrate so seriously that they were painted some forty years ago, and have been kept painted ever since. The same decomposition is taking place in some of the beautiful marble used in the decoration of the Chapel of Durham Cathedral.

Sandstones are generally supposed to be composed of quartz sand, cemented together by different kinds of binding material, such as quartz itself, as is the case with the Potsdam sandstone; with oxide of iron, as

in some of the sandstones of New Jersey and Connecticut; and with carbonate of lime, with or without oxide of iron, as is the case with most of the stone of Trinity Church, and of the ordinary brownstone which is so extensively used in the construction of the fronts of our city houses. In some cases clay is the binding material of the sand, and in others it appears to be some organic compound which easily decomposes.

When the material of which the stone is composed is fine, it is called a sandstone; when it is coarse, it is called a conglomerate. When the pieces are of the size of a hickory nut, and, as is frequently the case, of various colors, it is called a pudding-stone. When the pieces are angular, it is called a breccia. Where such siliceous rocks have undergone metamorphic action, they are frequently changed to quartzites. I have often seen a fine-grained quartz sandstone, under the prolonged action of heat in a furnace, without however melting, turned into a nearly compact quartz, with a glassy luster, having very much the aspect of a glazed porcelain. A striking example of this phenomena is in the metallurgical collection of the School of Mines. From a simple inspection there does not seem to be the slightest relation between the stone before and after metamorphism. The stones, however, that are composed altogether of quartz, are of rarer occurrence than is generally supposed. The materials making up the rock are of variable composition, and include a great variety of minerals which seem to have come from previously existing rocks, which have been ground up and subsequently cemented together. In most cases the minerals contained in the stones have retained the characteristic qualities that they had in the original rock. The microscopic bubbles can still be seen moving, as they have been doing since the ages of their formation. The feldspars retain their characteristics, and the fact that the rock of which the sandstone was formed was sound, or was undergoing decomposition at the time of its destruction, may still be seen in the sandstone.

The structure of the stone is very different, not only from the different kinds and sizes of the grains which compose it, but also according to the greater or less amount of pressure exerted at the time of its formation. In some, the consolidation is so loose that they are manifestly unfit for constructive materials; in others, there is every degree of real or apparent compactness. In order to fix a rule, it has been stated that those stones which, in a climate like our own, effervesce slightly with acids, weigh less than 130 pounds to the cubic foot, and which absorb

in the course of twenty-four hours over five per cent. of water, cannot be good stones. Many of our sandstones, after having been exposed to the weather for a considerable length of time, will absorb anywhere from three to fifteen per cent. of water in twenty-four hours, and consequently stand but a short time in a building.

When sandstone, which has a laminated structure, is not placed in its quarry bed, it is impossible that it should stand in the building for any great length of time, unless the binding material is quartzose. Sooner or later, from the effects of the weather, lamination will take place, and this may be seen in most of the sandstone pillars so common on the fronts of houses in former days, and on some of the ornamentation of the beautiful entrance to Greenwood cemetery, which is being rapidly destroyed in some of its upper parts by this cause, as well as decomposing from other causes in other parts of the structure.

Decomposition occurs most rapidly in those sandstones having organic or argillaceous binding materials. The former are decomposed by the weather, the latter very rapidly swell and disintegrate the stone, and very soon obliterate all traces of mouldings. Those having a ferruginous gangue are more suitable, unless the iron has come from the decomposition of pyrites, in which case the excess of sulphur renders the stone likely to disintegrate. In some cases the causes which have produced the precipitation of the iron, which binds the sand together have acted very unequally, so that the stone is hard in some places and soft in others, and consequently resists the action of pressure unequally in different parts.

Most of the New Jersey sandstone has either an argillaceous or calcareous binding material. Both are easily acted upon by the weather in the country and by the gases of the city, especially at points near the ground, or where the mouldings are improperly cut, so that the water is not shed from, but remains on or filters through them. Examples of this may be found in almost every street in large cities where brownstone is used. The same kind of decay may take place at or above the level of the ground from a different cause. If the superstructure has not been provided with a damp course, the moisture will rise in the masonry as high as 8 or 10 feet, the effect being the more prominent as the walls are thicker. If, in addition to this, the surface drainage is toward the building, instead of away from it, the quantity of moisture will be all the greater. Exactly the same effect is

produced when the water from the roof is not absolutely cut off from the vertical walls of the building. In old buildings little or nothing was done to prevent this action except the drainage of the foundation. When the foundations were properly drained, and the stone used in them had a siliceous cement, the bad effect was exceedingly limited in extent, and did not usually show itself until after a long period of years. When, however, the stone was a limestone, or had a calcareous binding, this was slowly but surely dissolved out, the effect being all the more rapid as the locality was more densely populated. In order to prevent this action, the outside of the foundation walls against the earth is covered with asphalt, and what is called a damp course is frequently made by spreading a thin layer of asphalt over the horizontal surface of the wall above the ground so as to prevent the water from passing up into the walls of the building. If there is no protection from dampness, as in most old buildings, and the situation is a moist one, there is then another difficulty which hastens the decomposition of the stone, which is, that on the north side the stone is uniformly moist, while on the south it is, from its greater exposure to the sun, dry and moist alternately. As the moist side is already near its point of saturation it sheds the water, while that which is dry absorbs and then sheds it, carrying some soluble material with it.

When in sandstones the binding material is oxide of iron, there is frequently only just enough of it to hold the sandstone together, so that the least decomposition will cause the stone to disintegrate. Such stones as these, where there is a minimum quantity of binding material, are always rapidly decomposed when subjected to atmospheric influences.

Of the sandstones having a siliceous binding material, the Potsdam sandstone, which has been used in the recently constructed buildings of Columbia College, and the siliceous triassic sandstone which was the material used in the lower part of the Cathedral at Rodez, are the best examples; and in these no decomposition takes place. Of these sandstones it will be noticed that there are two general varieties, one in which the quartz grains are more or less large and are rounded, but are cemented together by silica, a variety which may be found in any quarry from which brownstone is taken, and is the only variety of that kind of sandstone which should ever be used for building. In the Potsdam sandstone, on the contrary, the grain of the quartz is quite small, its shape, when it can be distinguished at all with a magnifying glass, is always angular.

The stone is porous, but is cemented by silica, so that it appears, on a cursory examination, to be quartzite. This is the best of all building materials, though mouldings made of the other variety will last for many years, without suffering any appreciable amount of deterioration. The Potsdam sandstone has been but recently introduced into New York. It is an excellent building material. Almost the only objection to be made to it is that it is difficult to obtain it in large pieces.

The siliceous variety of the ordinary brown sandstone may be seen in any house where brownstone is used, in any large city. It has often been the case, that in examining houses where the decay has gone on to such a degree as to almost make it necessary to take the fronts down, certain of the stones that were composed either of pebbles, or of less coarse grains cemented by quartz, were still so sharp, having undergone no decomposition of any kind, that they could be put back into the building with perfect safety. This is true, not only of the facings of the building, but of the ornamental stone-work around the porticoes of the houses. If the selection of only such stones as have a siliceous cement had been made from the quarry—as it undoubtedly was by the masons, who, at the time that the Cathedral of Rodez was built, were a religious order—we should probably have had little experience of the decay of sandstones. Those men selected from the quarries only such stone as they knew from tradition or their own experience was most suitable. It is a curious fact, and a standing monument to their knowledge, ability, skill and conscientious work, that many of the sandstone buildings which they constructed are still standing without serious decay, while those built later on, are either on the way to ruin, or are already in ruins.

All of the different kinds of weathering on the brown sandstone can be distinctly seen in Trinity and St. Paul's churchyards. There is every gradation of it, from the stone that shows no trace of ever having been cut, and is just crumbling to sand, to that which stands apparently as fresh as the day it was put up. That careful selection of the stone is all that is required to have it last, is shown by the fact that there is in Trinity churchyard a brownstone head-stone, cut on both sides, bearing the date of 1681, which still shows the marks of the tools used to cut it. It is but little pitted, though it shows the marks of age. Others in St. Paul's churchyard just as sharp, and showing also the tool marks, bear the dates of 1760, 1766, 1770, 1781, 1787, 1793, while some of 1733,* and

* In St. Michael's churchyard, Charleston, S. C., there is a cypress-wood head-board, erected to the memory of Mary Anne Luten, who died in the year 1740, which is still in good preservation, and likely to last many years.

a little later, seem to have just started to crack, and many of later date have crumbled to sand. All of these stones stand vertical. That to the Rev. S. Johnston, President of Kings, now Columbia College, erected in 1758 on the north side of the tower, was so defaced that it was recut in 1883. The one to Mr. Faneuil, which lies flat on the north side of the church, which was erected in 1719, has the inscription still sharp. Most of those put up within this century have the dates barely visible. One sharp stone, erected in Trinity churchyard on the south side of the church, on Broadway, bears the date of 1746, and beside it is one of limestone, bearing the date of 1793, the inscription on which will last but a few years longer. Comparatively few of the stones erected after the commencement of this century are well preserved.

The causes of the decay in all of these stones are the solution of the binding material, and consequent deterioration of the strength of the stone; or, where the stone is weak in some parts and strong in others, as in the case of many of the ferruginous sandstones, the part of the stone unable to bear the pressure yields, throwing the weight upon the rest of the stone, which having too great a pressure upon it also yields, and the stone fails entirely. Where the binding material is lime, the cause of the disintegration is the action upon it of the minute quantity of carbonic acid, and sulphurous and other gases, dissolved from the air in the rain water, which readily attack the surface of the stone. If the mouldings are improperly cut, so that the water remains on them for any length of time, or passes through them, it may be that the surfaces of the under sides of the projecting pieces, such as balconies or projecting sills, which are improperly drained, and places where either the snow and ice of winter or the water of ordinary showers may rest, so as to become either absorbed in the stone or to pass directly through it, carrying with them some of the binding material in solution, which eventually becomes entirely dissolved, will become either partially or wholly disintegrated. Such is the case with the very thin mouldings which form the tops of the windows of the highly-decorated houses built at the time this sandstone was first introduced.

The effect of the small amounts of city gases absorbed by the water in dissolving out the binding material of the stone, can be most distinctly seen wherever there has been a leak which has caused a permanent drip over the surface of the stone. Here not only the change of color, but the pitting from the solution can be most distinctly seen. It

is as true in nature on a large scale as in the laboratory, that the lime and magnesia is less soluble in concentrated solutions than in diluted ones. The amount of carbonic acid in the water and the air at any time is extremely small, but the accumulation of very minute quantities, acting over a large area for a considerable length of time, has, in many instances, been sufficient to dissolve out the whole of the binding material, leaving little else than a skeleton of sand. Where there are two binding materials, one of which is lime, the solution of the latter leaves the stone porous. When oxide of iron is the binding material, this is easily dissolved out, though not so easily as the carbonate of lime, unless the iron itself has come from the decomposition of pyrites, when it contains sulphur, in which case its oxidation would cause the solution of some of the binding material, which would also be acted on by the organic and mineral acids contained in the city gases. The decomposition of some of the sandstones of the coal formation in Kentucky is both interesting and peculiar. These rocks are of variable texture, being in places coarse and forming conglomerates, while in others they resemble a very uniformly fine sandstone. When this fine-grained rock is first exposed, it is quite hard. It stands up against the weather on all sides except the north. On this side it disintegrates and falls to sand, in irregular caves, often 10 or 15 feet high, forming by its disintegration the only pine lands of the district. This cave forming takes place horizontally and vertically at the same time, leaving a thin hanging front, which to all appearances from the outside is solid rock. After some time, holes of irregular size form in this front, which eventually breaks down, as does also the overhanging rock, when it can no longer bear the weight above it. In this case the disintegration is caused by weakness from the loose consolidation of the grains of sand.

The decomposition of the sandstones shows itself in several ways. The first and the most general one is by flaking, where large pieces, apparently parallel to the stratification, chip off, to the depth sometimes of a quarter of an inch. When these are examined carefully, they do not always show any trace of following the strata of the stone. This flaking does not take place until most of the binding material has gone, or been entirely dissolved out. Whether this material is of an organic or mineral nature, the depth of the decomposition will determine the point at which it flakes. The least blow, or a hard winter, or the infiltration of water which freezes, or the accidental arrangement of a series of mica plates,

will determine the point as well as the moment at which it will fall. Sometimes, when this cause exists only to a small extent, or when there is a cavity in the stone, it will begin to bulge away from the sides, and may even crack out by the infiltration of moisture, when that moisture is caught in the interior and freezes. This frequently takes place over roughly finished surfaces, as the projecting fronts over doorways, which, when the phenomenon commences, sound hollow when struck, and are then entirely at the mercy of the frost, which will eventually break them to pieces. I have frequently seen slabs on the upper parts of stoops, five feet square, which were detached from the underlying stone in this way, in the center of a larger slab, which remained in this condition for several years, showing no trace of decomposition on the surface, and which were finally detached from it either by an accidental blow or by the heaving of the frost. When such slabs are once broken or cracked, the pieces rapidly flake off. It is asserted by some stonemasons that flaking may be produced by improperly dressing the stone; that where the surface is dressed by the blows of heavy hammers, particularly if a large number of blows are made in regular time by a uniform movement either of machine or hand, the surface of the stone becomes so fatigued that there is a tendency toward the separation of the grains, and that a stone so dressed will eventually laminate. Whether this be true or not, it would only account for a part of the difficulty. Although this method of dressing has been very generally abandoned for the planing and polishing machines, there is no diminution of the lamination of these stones.

I have tried filling the cavities made by fracture out of a laminated surface in such stones with stone putty or cement, but never have been able to keep them from breaking off on horizontal surfaces. I have sometimes been able to hold them in place for a few years with shellac on a vertical surface. That the decomposition has gone beyond the pieces flaked off may be seen by examining the surface of the stone from which the flaking has taken place with a glass, even when the fresh fracture has been exposed for but for a short time only. On looking carefully at it, it will be found that the surface is pitted. This pitting on the outside surface is generally taken for hammer marks, but on examining it carefully it will be seen that the stone has become open and that it has changed color. This change of color is owing to the deposit of a certain amount of soot at the bottom of each one of these holes, so that the

change is an apparent and not a real one. This pitting not unfrequently extends through the flake to the surface of the stone below. If examined carefully at this stage, it will be observed that the pitting is owing to the fact that the binding material has been dissolved out to a considerable extent. When such stones are examined with the mircroscope it will generally be found that the pitting, which is all that is at first visible, has been accompanied by a honeycombing of the stone, which appears as if riddled with minute holes when the pitting has gone deep enough, and that the binding material, of whatever nature it might have been, has been either partly or wholly removed. This is especially true when it is carbonate of lime, or when there has been any cause of weakness, such as the presence of minerals which have a tendency to assume specific directions. Any cause which will produce an unequal expansion, such as the freezing of the water infiltrated, or the exposure of the surface to a very hot sun, will have a tendency to cause the stone to break off in thin lamellæ, or to flake. Pitting as it usually occurs in the brownstone of the city, cannot generally be seen by the eye, and can only be observed by a careful examination with a glass. Occasionally a thin flake of the decomposed stone is sufficiently honeycombed to allow the light to pass through the fine pin-holes. Sometimes, however, as in the stone of Castle William, on Governor's Island, it is quite deep, in some cases in rounded, but oftener in elongated holes, which have penetrated the stone a quarter of an inch or more. When the pittings are so large as this the stone does not flake, but falls into sand.

Sometimes the stones do not flake, but simply crumble over the surface and at the sharp edges. This occurs where either the angles have been too sharp for the stone, or where the stone has not been properly undercut, so that the water passing through dissolves out the binding material and leaves nothing to hold it together. This kind of decomposition takes place in the quarry as well as in the structure, and may have taken place to such an extent that the stone is worthless to a very considerable depth. I have known of some cases when it was necessary to strip the sandstone of a quarry for 20 feet before arriving at any sound stone. It is said that in opening new sandstone quarries the rock for 2 to 3 feet can be removed with a pick, and that it is generally necessary to reject the stone for several feet. It is, therefore, not safe to use a stone from a new quarry without first making a complete microscopic examination of it, which should be supplemented by a

partially chemical one, to ascertain first whether the stone is sound; secondly, whether it contains any material which will be likely to be either decomposed or be absorbed by the action of the elements. With the sandstones that are very porous and have lain in the quarry bed, the mere freezing of the water absorbed will be sufficient to flake off part of the surface; or, when that does not take place, to crumble the stone considerably.

It was formerly the practice to require by contract that the stone should be exposed to the air for a certain time after being taken from the quarry to season; that is, have the quarry water dried out of it, and to ascertain whether there was any commencement of decomposition or disintegration in any part of the stone. This was the practice of most of the ancient architects. Sir Christopher Wren required that the stone for St. Paul's Cathedral, in London, should season for two years after it was taken from the quarry before it was put into the building. It is well known that stones with the quarry water in them are much softer than after exposure. This is particularly true of the soft limestones of Paris, which can be easily cut with chisel and saw and planed with a plane while the quarry water is in them, but which afterwards become quite hard, so as to very considerably increase the expense of dressing them. It has been frequently remarked that when stones with the quarry water in them are exposed to the temperature at which the water freezes, they chip much more readily than when, after it has once been dried out, they are exposed to moisture. The explanation which has been given for this is that the quarry water contains salts in solution, which, on the evaporation of the water, bind the stone together, and thus make it stronger. Whether this is so or not, it was well known to the ancients, and it has been shown by modern experience that a tempered stone lasts longer than a fresh one, and the fact merits the attention of builders. It often happens that decomposition may have gone on in certain localities to the depth of three to four inches without its being perceptible on the surface. Where iron pyrites, in any shape in which it can decompose, is present, this will act upon the various kinds of binding material, and cause the stone to disintegrate.

The causes of decay then are: first, improper selection of the stones in the quarry; almost every sandstone quarry contains poor stone, as well as that which will last for a great length of time, and this can always be dis-

tinguished because it is highly siliceous, and contains no traces of mica, and but little material soluble in acids. The presence of mica is essentially bad because it shows a probable tendency to lamination in the stone. Where the stone would otherwise be good, the improper cutting of mouldings, and especially the want of undercutting of projecting mouldings, so that the water will be shed instead of running up over or down through, is the most fruitful cause of decomposition in the buildings of the present day. Where the edges are very sharp, there will always be a tendency, by capillary attraction, for the water to run up until it meets some point so ascending that it cannot follow up, and from here it will drip without passing through the stone. Where the surfaces are flat, crumbling or lamination will take place; where they are thin, so that the water will pass through them, the stones will crumble and flake; and where there are large surfaces immediately under projecting mouldings, in such a condition that the water will flow up over the moulding, and then slowly down the face, lamination will take place. It is a remarkable fact, in looking over buildings that have undergone this decomposition, that the greater part of it will be found within a comparatively short distance from the ground—generally within ten feet. From this point it gradually diminishes up to about 50 feet, where it ceases entirely, unless there is some action of sulphurous gases, or the acid or alkaline gases from the combustion of wood or coal, or from manufactories, coming in contact with the stone. In all the buildings that I have had occasion to examine, beyond one hundred feet there is not only no decomposition, but the stone is harder than it appears to have been originally. The same stone which would last almost indefinitely when put into a building in the open country, with no other buildings near it, would be subject to decay in the city. The present mania for high buildings, if it had not been stopped by law, would have increased this decomposition, and would have greatly raised the maximum height to which it would reach.

The stone of which Trinity Church is built is a red sandstone, which has always been supposed to be homogeneous, and, until the decay which has become manifest within a few years, has always been supposed to be one of the stones that would resist the action of the weather. The investigation which has been made,* has shown not only that there are different

* The microscopic examination of the specimens taken from Trinity Church was made by Dr. A. A. Julien, of the School of Mines.

kinds of stone used in the building, but that none of the varieties are, strictly speaking, homogeneous; for, instead of being composed entirely of quartz grains, united by a cement, they contain not less than twenty-eight different varieties of minerals, embracing twenty-five species, some of which are quite susceptible of decomposition, and many of which have begun to decay in places, and this process is still going on. The following is the list of the minerals found in the sandstone of Trinity Church:

Quartz,	Biotite,	Calcite,
Amphibole,	Hydro-biotite,	Dolomite,
Epidote,	Sericite,	Magnetite,
Garnet,	Margarodite,	Hematite,
Oligoclase,	Fibrolite,	Limonite,
Orthoclase,	Brown tourmaline,	Göthite,
Microcline,	Green tourmaline,	Pyrolusite,
Kaolin,	Indicolite,	Rutile,
Muscovite,	Cyanite,	Asphalt.
	Apatite.	

In addition to these, there is a considerable quantity of opacite, a name given by Vogelsang to the black opaque grains and scales which so frequently occur in rocks, and which cannot be identified with magnetite, menaccanite or any other mineral. What is more remarkable in this enumeration of species is the complete absence of pyrites. All of this stone contains a considerable quantity of material easily soluble in acids, most of it effervescing, a certain portion of it going into solution with the greatest ease. If the stone had been properly selected at the time of the building of the church, or if the mouldings had been so constructed as to shed water, I think there would have been but little decomposition at this time, but without some protection it must eventually have taken place.

The depth and kind of decomposition differ in each variety of stone, but all have undergone more or less of it, and wherever any of the stone lies below a projecting piece, the decomposition has gone on to a very considerable extent. After selecting the pieces that were more or less affected, I succeeded in getting a piece of the stone which had been lying exposed to the weather until within four or five years, and had then been accidentally buried. I had it dug up and left exposed to the

air for some time, and then carried to the cellar of the church, where it was dried at a temperature of about 60 degrees for two or three months before the specimens for examination were taken from it.

The decomposition shows itself in these stones in three different ways: first, by deep pitting and falling out of grains of the minerals which compose the stone; second, by lamination; and third, by crumbling to powder. The way in which each one of these is effected depends upon the position of the stone. The pitting is quite irregular, and is due to the removal of the cementing material from the surface; and where this has been done by the action of the weather, there seems to have been a deposit of sooty material at the bottom of the depression which has slightly changed the color of the stone, so that the outside is of a different tint from the inside. The cause of this is not shown until the stone is examined with a microscope of high power. On treating such a stone as this with acid, generally no effervescence takes place, and very little of it is soluble. The same is true, but to a less extent, where the rock has flaked. The flaking does not appear to be owing to the fact that the stone has been used in a different position from that which it held in its quarry-bed, though in many places it has evidently not been placed in its natural position; nor to the fact that the stone is laminated, owing to the presence of large quantities of mica; but it is owing to the absorption of the cementing material by atmospheric influence. It is also to be observed that there are in many sandstones which are used for building in this city, organic materials which act as the cement, and are easily decomposed by exposure to the weather. Stone of this kind, except to a very limited extent, does not seem to have been used in the walls of Trinity Church, though it is extremely common in other parts of the city. It can only be kept from complete disintegration by filling the pores of the stone with some substance which will prevent further encroachments of the weather, which must be renewed from time to time as it is decomposed or dissolved out. By the original agreement, the stone of which the church was built was to be taken from a single quarry, which had been determined by observation to give a strong stone, but this agreement, like that made for the stone of the House of Commons, in London, was not adhered to. The different varieties of stone used in the building are:

First.—Fine-grained, lamellar reddish-gray. Of this variety there were 15 specimens.

Second.—Fine-grained reddish-brown. Of this variety there were 6 specimens.

Third.—Fine-grained light gray. Of this variety there were 6 specimens.

Fourth.—Coarse yellowish-gray. Of this variety there were 3 specimens.

While the varieties examined were most of them weathered, specimens of these varieties are easily distinguishable in the unaltered stones of the building itself. The stone was, for the most part, of the same origin, having had in the quarry a calcareous cement. It does not appear that any large quantity of this stone would have endured exposure in the quarry or in the building for any great number of years without being affected. None of those which had a siliceous cement appear to have been decomposed. There are two types of the first variety of stone, distinguished as A and B. Both of these were taken from the piece that had not been exposed in the building. The type A was coarsely laminated and contained the following minerals: Quartz in very irregular grains, most of them rounded, some of them quite spherical, filled with minute bubbles either in motion or quiet, varying in color from smoky, through white to red; orthoclase, plagioclase, probably oligoclase, and microcline distinctly cleavable. These were the prevalent minerals. Magnetite and menaccanite in grains of varying size are quite evenly distributed. Biotite, hydro-biotite, muscovite and margarodite are quite regularly scattered through the rock; epidote in small particles, rarely in prisms; green and blue tourmaline in occasional grains; iron ochre and garnet in very small grains, and sericite in minute bunches around and between the grains of quartz and feldspar, are also found. Of all the minerals the micas are those which have undergone the most decomposition, the hydrated varieties appearing everywhere, and these frequently having become opaque from still further decay. The rock gave a lively effervescence with citric acid, showing the presence of calcite; apatite was also present in small quantities.

The composition was determined as

Quartz	57 parts.
Feldspar	31 "
Fine-grained minerals	12 "
	100

The rock was slightly altered, as were also the minerals that compose it. To give a fair idea of the amount of decomposition, the grains of about the same size were counted and classified according as they were more or less affected.

	Clear.	Slightly Cloudy.	Very Cloudy or Opaque.
Orthoclase.....	6	22	16
Oligoclase	4	1	
Microcline.....	1		
Hydro-biotite.....	14	14	12

It thus appears that the feldspars were the most decomposed.

The second variety of the stone, B, which had not been put into the building, had lain on the ground in the churchyard exposed to the elements for about 30 years. One part had been acted on by the weather, and was of lighter color than the rest, owing to pitting. Here the dropping out of grains of quartz and feldspar is distinctly visible, but all parts of the stone effervesced with citric acid. The specimen contained about the same quantity of quartz and feldspar as No. 1. Hydro-biotite, sericite, margarodite and amphibole are in elongated and crushed fragments; kyanite, blue tourmaline, hematite, magnetite, limonite and calcite were also found.

The way the alteration of the minerals which compose the rock had taken place, is given below:

	Clear.	Cloudy.	Very Cloudy.
Orthoclase.....	9	22	4
Oligoclase	11	2	
Microcline	1	1	
Hydro-biotite	3	1	2

The weathered part of this variety is deeply pitted, but there does not appear to be any appreciable widening of the distances between the grains, but the rock is honeycombed by the deeper of the pits going through the flaking; the calcite was entirely gone, no effervescence taking place in citric acid. The minerals themselves do not seem to have undergone any decomposition since they became incorporated in the stone.

Of the second variety there were two unaltered specimens, both of which were taken from the inside of the tower high up in the steeple. It contains much more ochre than the other varieties. The minerals

composing it are quartz and feldspar as before, brown tourmaline, sericite, margarodite, hydro-biotite, garnet, epidote and magnetite. It does not effervesce.

The proportion of the ingredients contained in the stone was:

Quartz	41
Feldspar	35
Cement	24

All the crusts are deeply pitted and honeycombed.

The third variety is fine-grained and indistinctly lamellar. The fresh specimen was taken high up from the inside of the tower. It effervesces rapidly with citric acid. The most prominent mineral is quartz, which is quite clear; the orthoclase is generally cloudy. The accompanying minerals are amphibole, garnet, margarodite, hydro-biotite, brown tourmaline and sericite. There is but little plagioclase. The following proportions of these minerals were found in three specimens:

	1.	2.	3.
Quartz	53	61	51
Orthoclase	22	17	39.5
Hydro-biotite	..	2	0.5
Cement	25	20	8.5
	100	100	99.5

The feldspar is whitish, the cloudiness being caused by a great abundance of microlites generally arranged in parallel planes about normal to the direction of easiest cleavage of the feldspar. Between these cleavages there is a slight transparent film of sericite which polarizes feebly. This mineral is probably the result of the commencement of the alteration of the feldspar, but in some of the grains the decomposition has not progressed further, while in others its progress is shown by the innumerable very small microlites which are quite colorless, but give a milky appearance to the grains where they occur. They are probably both sericite and epidote. The hydro-biotite is transparent green in the center, and opaque brown on the edges, showing a commencement of decomposition. The other minerals, margarodite, sericite, epidote, tourmaline, iron ochre, do not show anything peculiar. Where the specimen is not decomposed it is close-grained without interstices, when it is weathered it is honeycombed.

The fourth variety was coarse-grained yellowish. It is quite compact, so that little pitting is found on it. It contains no carbonate of lime. The quartz is in closely-packed grains, generally clear, but containing some inclusions. The grains are angular. The orthoclase is also angular, some of the grains being cloudy. The plagioclase is also angular, and polarizes the light strongly. The biotite and hydro-biotite are in yellowish-green scales. The other minerals are margarodite, epidote, amphibole, sericite, magnetite and iron ochre. No pitting occurs, except in the specimens in which there are red flakes, and here it is quite deep. The specimens where this occurs were taken from the outside of the church near the ground, where they were exposed not only to the action of the weather, but to that of the dampness coming from the ground as well. The composition of these specimens is given below:

	1.	2.	3.	Average.
Quartz	40	70	57	56
Orthoclase.....	53	18	31	34
Cement	7	12	12	10

With regard to all of the stones, it may be said that the disintegration is not caused by either the looseness of aggregation of the particles, nor by the structure of the stone. In all the specimens there was shown great compactness and no cavities, except occasionally when grains had fallen out owing to the absorption of the binding material. It was not influenced by structure, for while there is an abundance of mica, the splitting is as much across the mica plane as in it. If anything, the mica, though acted on, seems to have played, to some extent, the part of a binding material.

The disintegration is not owing to the decomposition of the feldspar, most of which belongs to the variety orthoclase, which decomposes with comparative ease. It is to be noticed that the average amount of orthoclase in the specimens examined was between 29 and 30 per cent. Most of these grains were more or less decomposed, but there was no evidence to show that the decomposition has progressed to any extent since the consolidation of the sand into stone. On the contrary, it seems to have been completely arrested. This is shown by the fact, that in the most highly-weathered specimens, the proportion of milky grains of feldspar showing inclusions and the commencement of decomposition is no greater, and the decomposition no further advanced than in the

fresh ones. The stone seems to have been formed out of the destruction of granitic rocks, which had commenced to decompose during the trias previous to their destruction, and to have been consolidated under immense pressure, as is shown by the crumpled and irregularly broken and curved mica plates, and the compact nature and close union of the grains.

It appears, however, that some decomposition has actually taken place in the minerals of the stone since its consolidation into rock form. This is shown in the condition of the iron micas, both the biotite and hydro-biotite, which contains from 5 to 25 per cent. of ferrous oxide, from 1 to 4 per cent of water, which readily decompose. That some decomposition has taken place in it is shown by the varying color of the mineral, individual pieces being mottled brown and green, and also by the action of polarized light upon them, as well as by the fact that their passage into chlorite and iron ochre can be distinctly seen. Part of this decomposition is seen in the unaltered stones, but it is much more prominent in the weathered ones, and while of itself it would have had but little influence in weakening the stone, it undoubtedly put the constituents into a form in which they would be more easily attacked. A very slight alteration in the margarodite, amphibole and garnet is seen. While this decomposition is not sufficient to account for the entire weathering of the stone, it undoubtedly contributed, although slightly, to it, as at the most it could weaken the stone but little. It is, however, to be observed that the mineral calcite is present in every one of the unaltered specimens except the last variety, which consisted of three specimens out of the thirty examined, and that in all the weathered varieties this was either wanting entirely or present in very small quantities, and that wherever it was dissolved out to a small extent, there the stone was pitted, and when entirely gone, honeycombed, rendering that part of the stone porous and open on the outside. How far the iron has been removed at the same time as the lime, cannot be stated. There has been no very great change in the color of the stone—certainly not sufficient for us to suppose the removal of any large quantity of iron oxide, and but little that may not be accounted for by the presence of small quantities of carbon deposited at the bottom of the pittings in the stone. The decay is deep-seated, penetrating, at times, several inches into the stone, which still looks sound on the outside, not showing the least trace of flaking; but in no case is the lime

entirely wanting from the interior of the stone, even when it has been entirely dissolved from the surface. The removal of even a very small quantity of lime would render the ochreous material which is so abundant much less stable, and far more likely to be acted on. It is not very homogeneous in any part of the stone, but is much less so where the calcite is gone. This action on the iron, while it could not go on at any great depth from the surface, and so could not weaken the stone much in the interior, was at its maximum on the outside of the stone; and, as it was already porous from the solution of part of its binding material, this rendered it likely to flake at short distances from the surface, the stone falling off in layers along the lines of least resistance, corresponding to the plane which included the greatest number of pit bottoms, and consequently give an appearance of lamination in the stone which did not exist in the stone itself. Frost would separate such stone into lamellæ very rapidly.

Independent of all these considerations, is the fact that there is in all these stones a certain amount of organic matter, which can easily be detected on heating the stone by the empyreumatic odor which it gives out. The microscope does not show any vegetable matter, nor, in most of the stone, any traces of carbon which is not in a state of combination. It is well known that organic acids form combinations with bases, which combinations are decomposed when submitted to the continued action of moisture, and will be all the more rapid as this moisture is slightly acid, as it is in all cities. It is most common to find, either in or in the vicinity of these rocks, large quantities of organic materials, either fossilized, such as plants, lignite, coal, asphalt, or combined with bases. Asphalt was actually found, in very small quantities, in two specimens of undecomposed stone. In other sandstones organic acids have been found. It is more than probable that they would be found much oftener if looked for. The expense of such investigations, however, generally prevents their being made. Dr. Julian has called attention to the fact that the ochreous condition of sandstones of different geological ages is not the same. In those of the paleozoic periods it is hematite, which frequently produces such a permanent cement as to make a durable building-stone. In the tertiary it is turgite or limonite, and in so small quantity as to produce in many cases only sand rocks. I once had occasion, in the Far West, to examine the abutments of a railroad bridge built of stone excavated in the winter from such a quarry, and

found that the rock, though apparently strong, could be rubbed into sand with the fingers. In the sandstones of intermediate geological ages, göthite predominates, and is in variable quantities in different layers of the same bed, making the rock correspondingly strong or weak. The range of the variation is so great as to imply the possible association of organic acids with the iron oxide. Whatever may be the cause of the decay, it is not loose consolidation of the rock. It is not wholly explained by the solution of the calcareous matter, but is undoubtedly hastened by it. It had progressed somewhat in the quarry before the stone was put into the church, and is still going on. The flaking of the stone in thin parallel layers is perfectly explained by the solution of the lime, but the deep-seated decay needs further study, as the action of the acid, waters and gases does not fully explain it. The flaking is hastened by the heat of summer and the frost of winter, and is always most prominent where there is any drip of water.

It is certain that the decay can be retarded, even in the buildings which were constructed twenty or thirty years ago, so as to make them last for many years. It is not certain that it can be completely arrested. The decay in Trinity Church is one of the best examples that could have been chosen, for it applies to one of the most compact and well-selected building stones of the country, which was selected at the time on account of its supposed great durability. It is certain that from the same quarry, by a careful selection of stones with siliceous binding materials, and the rejection of all others, material might have been selected that would have lasted indefinitely.

It has been usual to consider all sandstones as good for building purposes, or not, according as they were compact or more or less porous, and this rule has undoubtedly influenced the choice of the stone which has been used, which is in this respect an extremely good one. The theory generally accepted is that the porous stones absorb moisture, which in the cold of winter freezes and, expanding, disintegrates the stone; and that the heat of the sun also contributes its share to the expansion, which causes the flaking. This cannot be said to be true to any great extent of the stone of Trinity Church, except where the moisture, from the defective cutting of the mouldings, has not been shed from the surface, and has been constantly dripping on the stones below. It is specially observable that on all the faces of the building underneath projecting stone, whether it has had mouldings cut on it or not, the stone

has decomposed more or less. It is a remarkable fact that in all of the specimens taken from all parts of the church, both inside and out, and representing so many varieties of stone, no iron pyrites has been found, and consequently no such cause of disintegration as often produces decay in other building materials can be ascribed to it.

The microscopic examination revealed the fact that a considerable quantity of carbonate of lime was contained in most of the specimens, the fresh stone containing the most; and that in all. the decayed crusts the lime was present in very small quantities only, or not at all; and in many cases this decomposition has gone on to some extent, even to the depth of eight or ten inches in the interior of the stone, without showing any trace of decomposition on the outside. The stone was thus rendered extremely porous by this solution, even where the weathered exterior retained the smooth surface of the original dressing. It therefore was porous in the interior as well on the surface, and was subject to decomposition in all its parts. This is shown to take place far into the interior, even when it appeared not to be affected on the outside at all. I was not able to find a single specimen of the stone in any part of the building that had not apparently undergone this action to a certain extent. In some few cases the pitting is owing to the dissolving out of a small amount of the oxide of iron, which serves the purpose of an additional cement; but it is generally the carbonate of lime which has been removed.

In every case—and but few such were noticed—where the stone has been set upon its edge, the lamination has gone on to a considerable extent; but, what is more remarkable than this, is the fact that all of this stone in every part has undergone more or less of this interior decay, which seems to extend through the whole stone, and in some places where it was particularly weak has caused the bulging of the face in thin laminæ, even where the stone has been laid in its quarry-bed. In a very few instances it seems that this bulging may have been owing to a decomposition of some of the minerals contained in the stone.

None of the causes which are usually alleged to account for decay seem to be prevalent here. These are usually a loose consolidation of the sand of the stone, owing to the fact that the cementing material is not quartz, as it is in the Potsdam sandstone used in the new buildings of Columbia College, but is some material subject to decomposition. The true cause of the decay seems to be the fact that, owing to the defect

of the undercutting of the mouldings where there is a drip, the water remains in and is absorbed by the stone, and in some cases passes through it. Every shower of rain, particularly in cities, removes a very minute amount of binding material from the outside. When the stone is soft, owing to the small quantity of binding material contained in it, the action is comparatively rapid; and if to natural causes are added the corrosive gases of the city, decay will be very rapid. This decomposition goes on most rapidly under projecting horizontal pieces. The flow of rain water over a vertical surface of stone injures it but slightly, only that which is absorbed affecting any damage. The rest is so rapidly shed that it has no time to dissolve out anything. When the water is rapidly shed, the solution of the binding material is uniformly slight, as the evaporation of the water leaves all the solid parts which it may have dissolved, behind. But when the water passes through the stone, or the quantity dripping on it is such that the stone cannot absorb it, so that it either passes directly through or runs off from the surface in more or a less of a stream, then the quantity actually dissolved out will always be a maximum. It is to be remarked that the places where decay exists are precisely in these conditions. In the country this would probably have but little effect, and the building would last a long time; but in the city air, which is charged with a larger quantity of carbonic acid than is usual in country air, and also with small quantities of sulphurous and sulphuric acids, and with all the acid gases that result from the decomposition of city refuse, which are absorbed by the water, it has the power of dissolving the cement of the stone even though in minute quantities, and, after a considerable period, renders the stone so loose that after a time it will flake and fall to powder, or become disfigured. As soon as this state of things was suspected, a careful chemical examination was made of five of the stones of the church taken at random, selecting however one, No. 1, which was fresh stone.

The analyses of these stones is given below. They show that in the weathered specimen a large quantity of the binding material has been dissolved out, leaving the stone in a condition to be acted upon by all the decomposing agencies of the weather, as frost, expansion from heat, expansion from cold, and the tendency which decay always has to spread when it has once begun.

	No. 1.*	No. 2.	No. 7.	No. 10.	No. 21.
	Fresh unexposed stone.	Weathered. Outside of No. 1.	North side tower base and buttresses.	South side between 6th and 7th buttresses.	South side base between 4th and 5th buttresses
	Interior.		Scales.'	Scales.	Scales.
Insoluble.....	90.30	91.64	96.09	95.82	94.27
		Soluble.			
Iron oxide.....	2.25	2.66	2.32	2.39	1.97
Lime.....	3.61	2.45	0.26	0.14	1.51
Magnesia.....	0.30	0.36	0.28	0.27	0.20
Carbonic acid, organic matter, etc.....	3.54	2.89	1.05	1.38	2.05

In all of these stones there is a small amount of organic matter which gives a peculiar smell when burned. In many of them no trace of effervescence with acetic acid could be seen under the microscope, and after careful drying in an air bath the total amount of soluble material did not exceed three per cent.

The examination shows that there is no cause of decomposition in the stone itself; that the decomposition has gone on in all parts where the stone has been exposed to the air, whether inside or outside, with regularity; that most of the stone in the interior, or at a certain distance removed from the surface, is in about the same condition in which it was in the quarry; that the mere action of moisture, or of the air, affects the stone very slightly when there is only a vertical wall to be acted on. The decay of the stone is, therefore, owing to causes which act from the outside entirely, and it remains now to consider what will be the best method of adding something from the outside of the church which will prevent further attack upon and consequent decomposition of the stone. This is a matter of great importance, for, until the flaking of the stone, it was always supposed that the stone of this church would not decompose. The greatest care was thought to have been taken in its selection, but the investigation shows that the solution of the ingredients of the stone of one of the best buildings of the country, from the outside, has gone on to such an extent as to cause the stone to decay very perceptibly in

* These analyses were made by J. B. Mackintosh, E. M., of the School of Mines.

less than forty years.* I am glad to be able to call attention to the probable solution of the problem, which, if not soon solved, will make most of the handsome edifices of New York ruins in the course of a few years.

The methods for the preservation of stone are, first, properly inclined surfaces that will shed the water so that it cannot stand on the surface; properly undercut mouldings, so that the water cannot creep up under and remain so long as to dissolve out the binding material; keeping out the water as far as practicable. This must be done by waterproofing, so to speak, the foundations: placing a thin layer of asphalt between the foundation stones and the vertical walls of the building proper, 2 or 3 feet above the ground. This would prevent the slightly acid waters from the earth rising and decomposing the lower tiers of stones. Asphalting the fronts of the foundation walls themselves, previous to throwing the earth back against them, would prevent the entrance of a considerable amount of water, so that if the face of the foundation next the soil and its top were asphalted, the water would not enter here.

If the stone has been already acted on, and is to be preserved, something must be added to the outside to fill up the pores formed by the solution of the binding material, and prevent further encroachment of the water containing the acid gases in solution. To heat the surface of the stone, already weakened by decay, is only to make the decomposed surface more liable to flake. It must, therefore, be applied to the cold stone. Anything that forms a gum that is impervious to water, and can be made sufficiently liquid to penétrate the pores and pittings of the stone, will answer the purpose. Bees-wax or rosin dissolved in any of their solvents, with or without oil, have been used. Boiled linseed oil, which forms a gum, does very well, and only slightly discolors the stone for a time. But all of these substances decompose after a few years, and must be renewed. Paraffin dissolved in boiled oil, and put on hot, answers better, as it is more effectual, and after one or two applications will fill the pores completely. But no substance applied after decay has begun is equal to a preventive, and no preventive can preserve flat surfaces and projecting mouldings which are not undercut, from decay. Water-glass associated with a bituminous substance, a preparation known as Szerelmy's compound, was used on some of the interior

* All the decayed surfaces of the stone of Trinity Church were recut in the summer of 1884.

courts of the Houses of Parliament some years ago. I inspected all of these courts in the summer of 1884. The dilapidated condition not only of the finials, but even of the flat surfaces of the stone, showed that it had not even been a palliative.

About the year 1868, the Vielle Montagne Co., of Liege, introduced the process of painting with water-glass and oxide of zinc. This was applied to the railroad station at Liege, and to parts of the Houses of Parliament. A silicate of zinc and lime is thus formed on the outside of the stone, which indurates it superficially. The want of penetration, or careless application of the material, makes the surface flake, and it, like all other paints, requires frequent repetition.

Ransome's process, which consists of using water glass, with a subsequent application of some chloride, answers very well, but is a very expensive process, as it requires that the stone should be entirely refaced, in order to clean it. This, and the number of applications of the silicate, and subsequent application of the chloride, consumes so much time, and is so expensive, that it cannot come into general use. It has been applied satisfactorily to some small parts of the Houses of Parliament, but has been discontinued on account of its very great cost. The same is true of a number of other processes, which require first, the cleaning of the stone, and the subsequent application of several chemical substances, such, for instance, as the process of the Silicate Paint Co. They are excellent in themselves; they can be put on with certainty, when used with great care, and over small surfaces; but when they are to be applied to buildings already constructed, they either fail from the impossibility of applying them evenly on large surfaces, or become entirely impracticable on account of the expense. The principle of most of these processes is correct, and it is to be hoped that some corporation will find it to their advantage to have investigations made that will lead to the discovery of some substance which is both cheap and of easy application. Such substances undoubtedly exist, but they require to be sought for. Any process which requires the formation of a chemical union between the stone and the substance applied, must be put on in such a way as both to be certain of its penetration, so that the action will not be superficial, and to insure that the compound formed will not only become sufficiently indurated to withstand the weather, but sufficiently compact not only to resist the penetration of gas, but also to prevent the absorption of moisture, and to shed it at once from its surface.

Very few natural stones even do this, and they are the very compact siliceous stones, or dense carbonates, which are very homogeneous.

When oils, with or without paraffine and sulphur, are used for water-proofing stone, they should always be applied while hot, as they are then much more liquid, and, consequently, more effectual. It is better also that the application should be made when the stone is also warmed by the heat of the sun—that is, either in the spring, summer or fall, rather than in the winter. This application of oil, however is not permanent in its effects. The oil forms a gum in the pores of the stone, filling them up temporarily, so that the water does not enter, but after a time this decomposes, and must be replaced. It is very easy to distinguish the surfaces of stones that have been treated with oil, by observing them immediately after a shower, when it will be seen that the stone becomes dry much more rapidly than that which has had no such application. The necessity of applying the oil once in every two or three years is one reason why it is so little used. When paint is used, the solid material with the oil is of no account whatever. It remains on the outside, and does not enter the pores of the stone, and when the gum is decomposed it is washed off the surface. Another objection to painting the stone is, that while adding considerably to the expense of the process for protecting the stone, it adds nothing whatever to the efficiency of the oil, and it is very apt to fill up the fine tracery that may be upon the surface of the stone. It is, therefore, entirely unnecessary, and in some cases may be injurious, as preventing the penetration of the material which is designed to water-proof the stone. When oil is heated with an excess of sulphur it dissolves about 13 per cent. of it. More of it will dissolve in hot oil, but the sulphur crystallizes out upon cooling, and when there is a large excess of it, a partial decomposition takes place, and sulphureted hydrogen is formed. The oil, with the proper amount of sulphur, becomes thick and dark like molasses, but when heated is quite thin. When the stone is coated with this material it penetrates below the surface, and as the sulphur is simply in solution, when the gum of the oil decomposes it leaves the sulphur still in the pores. Two or three applications of such a material as this would prevent any further decomposition. It has been found by experiments made on the Houses of Parliament that sulphur applied in some such way has been the only thing that has arrested decomposition in that soft, porous stone; but even this preparation has not prevented the flaking of

the surface of the stone after an exposure of about twenty years, probably because it was not applied hot, and was put on when the stone was moist, or when the weather was cold.

If 20 per cent. of paraffine be added to oil containing the sulphur in solution, it thickens when cold into a semi-solid buttery mass, but is fluid when hot. Such a preparation as this, applied hot to the stone, gives another element with the sulphur, which does not decompose, to fill the pores of the stone. There may be cases in which it is undesirable and inconvenient to use sulphur, and in these cases 20 per cent. of paraffine mixed with hot oil may be used. The same is true of this as of the other preparation mentioned. The paraffine, which is, like the sulphur, practically indestructible, remains in the pores of the stone after the decomposition of the organic matter of the oil has taken place, and one or two coatings of such material as this will waterproof the stone entirely and prevent further disintegration. Other preparations of paraffine may be used to advantage, but those which involve heating the surface of the stone should be avoided. It has been suggested that these preparations discolor the stone. It is true that the color of the stone is darkened by them, but the stone is not disfigured, as the color given is very nearly uniform over the whole surface. In some cases the stones, after the application of the oil, have been washed with ammonia salts to take off the excess of the material from the surface. It is generally, however, undesirable to do anything to the stone after the liquid has been applied, as the surface will very soon become bleached by the action of the weather.

It has been objected to the use of oils that they would interfere with the adhesion of the mortar in the stone, if the stone were treated before it was put into the building. In actual practice, however, this does not seem to be the case. The stone is not only more thoroughly protected from moisture upon all sides, for in stone buildings in damp countries the moisture is as much to be feared on the inside as on the outside, but it does not seem in any way to deleteriously affect the binding power of the mortar. It acts advantageously both on the stone and the mortar, and does not influence any of the chemical changes that take place, either by accelerating, retarding or preventing them. This fact was well known to the ancients, for they used oil in mortars and cements to a considerable extent. When it is desirable to use soft and very porous stones for building purposes, the stone should be dipped either into boiling oil or some

such preparation as this, before being put into the building, so that its entire surface may be coated. The experience of the last thirty years shows that the stone cannot be perfectly protected unless this is done on all sides of the stone. Such coating does not in any way prevent the adhesion of the mortar if done either before or after it is put into the building.

In the experiments made in the year 1861, I was successful in preventing the further decay of a building which has, up to this time, shown no sign of lamination or disintegration. This was done by the use of thoroughly boiled oil alone, applied with a brush during the warmest of our summer weather, when the stone was very hot. It was done twice at intervals of several years, and completely arrested the decay for the time being. It would have been much more effectual if the preparations mentioned above had been used. The application of such material does not change the surface of the stone. It was used almost exclusively to porous sandstones. It seems to form a sort of cement, similar to the organic binding material which is so common in many of the brown sandstones, but with the limestones this has not been found useful to any extent. It requires renewal so often, and changes the color of the stone so unpleasantly, that it has not been found of service with these stones. Such preparations are, however, of no use on stones of whatever character, where the decay has been produced by disintegration caused by the unequal expansion and contraction of the minerals forming the stone. Such disintegration is very slow in most stones. It has taken thousands of years to produce it in the granites of the obelisks of hot countries. It appears to be more rapid in cold ones; but it takes place with unerring certainty and regularity in all those rocks where the minerals composing them have different rates of expansion and contraction. Here, as in the other case, there are cavities, but the filling of them does not arrest the decay, because it does not attack the cause. Nothing will arrest such decay, and no other decay in stone, except those caused by the air and water can be prevented by any application to its outside. It is therefore useless to attempt the preservation of such rocks as granite, since the unequal expansion of the minerals which compose the rock cannot be arrested by filling the cracks. They are applicable only to stones from which something has been dissolved out, leaving cavities which can be filled from the outside. Water-proofing the surface of a stone has the effect of keeping the water

out of pores that allow some of the constituents of the stone to be attacked, and is effectual in those stones only which are either porous by nature, or have become so by the solution of parts of their ingredients; but it has absolutely no effect where there is any movement in the particles which compose the stone, however this movement may be produced.

No method of protecting the surface of the stone of the Houses of Parliament has, so far, been successful, except where sulphur was dissolved and added to the outside of the stone, and this rendered the stone for a very long time water-proof. It had remained so for twenty years up to August, 1884, when I examined it, and found that it had begun to laminate, the part of the stone containing the sulphur peeling off in thin scales. The experience of the repairs at the House of Commons is that most of the substances which are supposed to be useful, are absolutely useless, if not positively harmful to that stone; that almost the only one that has been successful at all on these stones has been sulphur dissolved in some compound, and applied to the stone so that the sulphur itself was precipitated in its pores. But even this does not seem to have entered very far, and has not been successful unless the stones put in place of those removed had been treated on all their six sides. In that case the stone has been preserved, but how long it will remain so it is impossible to tell.

With dolomite, in which there is a large excess of lime, the only safety is to prevent the action of the carbonic acid contained in the air by water-proofing the outside of the stone. This can be less successfully accomplished, because, as the surfaces of attack are comparatively large, the action is from the outside, and but little pitting takes place, as the interlacing of the crystals makes cavities that never can penetrate far into the stone. Any coating applied to the outside will therefore be likely to wear off after a time, and thus leave fresh surfaces of attack, which do not at once become visible, as the surface is constantly kept clean by the rain and the wind.

All the experiments made in Europe with the use of silicate of soda, or water-glass, upon any building stones, except those in which lime and magnesia were principal elements, have met with signal failure. The use of water-glass or siliceous material amounts to nothing on siliceous rocks. The silica becomes decomposed by exposure to the air, and forms a sand which drops off, and the caustic alkali is washed out, or remains behind to help the disintegration. The only things which have been

successful have been those that prevented the attack of the acid gases or water from the surface or sides of the stone.

Water-proofing is best done by a compound of paraffine, sulphur, and oil, applied to the stones before they are put into the building, or else frequently applied to the surface after they are put in. In sandstones the sulphur is not necessary. Oil, with a certain amount of paraffine, may be used, providing the application is made hot. If, however, it is made cold, the preserving material sinks but a little way into the stone. If the stone is heated from the outside, with the intent to bring the surface of the stone up to such a point that it will heat the paraffine, there is great danger that the stone will suffer more from the remedy than from the disease.

There is no necessity for the decomposition of brownstone if the material is carefully selected. Every building that I have examined contains some stones that would last indefinitely, and if only those were selected from the quarry which have a siliceous cement, there would be no necessity for water-proofing, and we should not have the rapid destruction in beautiful structures which is so common in countries where sandstones are used. The same kind of external water-proofing must also be done upon dolomite and limestone, but efforts in this direction have been less successful than upon sandstones. Many methods for the prevention of disintegration have been tried, not only with no success, but with absolute failure.

DISCUSSION

On the Cause and Prevention of the Decay of Building Stones.

J. J. R. Croes, M. Am. Soc. C. E.—I would like to ask Professor Egleston with what kind of mortar he proposed to lay up his oiled stones?

Prof. Egleston.—I think any kind of mortar would answer perfectly, because the absorption of oil is not such as to prevent the chemical action in the mortar. The tendency of the oil would rather be to the center of the stone than to come out and affect the mortar.

M. J. Becker, M. Am. Soc. C. E.—Would this treatment be possible with stones coming fresh from the quarry?

Prof. Egleston.—Quite possible. It is desirable, however, that all building stone should be tempered before it is used, that is left long enough in the air to lose its quarry-water.

J. F. Flagg, M. Am. Soc. C. E.—I would like to ask whether soaking with oil in this way might not interfere with the adhesion of the cement?

Prof. Egleston.—I think not.

Mr. Croes.—Certainly it would not prevent the binding of the cement itself, but it seems to me that it would prevent that adhesion of the mortar to the stone which is essential to the mortar and the stone becoming one mass and holding firmly together.

Mr. Flagg.—Would not this treatment of the stone with the oil disfigure its appearance.

Prof. Egleston.—There is a difference in the absorption of the oil, and this causes a slight difference in color, which, however, disappears in a few months. If the stone is allowed to remain in oil or in fatty material for months until thoroughly impregnated, it might prevent adhesion of the mortar for a while; but the object is not to soak the stone through, but only to allow it to take up so much oil as to prevent the action of the water from the outside and the dampness from the inside.

Generally the oil is applied after the building is erected, but it is much better to water-proof each block before it is used. The object of it in this case is to prevent any action of the atmosphere; in the other,

it is generally to replace the material already dissolved out by some substance, which will fill the pores so left and prevent further attack. The substances so used are oil, sulphur and paraffine.

F. Collingwood, M. Am. Soc. C. E.—I wish to inquire of Professor Egleston on which side of the building, which exposure, he found most decay, and whether the common impression that prevails among masons is correct, that the smooth dressing of stone causes it to be affected more quickly.

Prof. Egleston.—There is no doubt that the smooth dressing of stone which has already begun to decompose will make the decomposition go on more rapidly. As to your other point, the direction of the prevailing wind, which regulates the storms, is the one which affects the stone the most.

Mr. Collingwood.—I ask that question because Professor Trowbridge, in an address he made, said that a southerly exposure was the one that damaged the stone the most. He attributed it to the heat.

Prof. Egleston.—After the decomposition has taken place in this sandstone, with absorption of moisture in the winter time, there will be a certain amount of freezing, and when the stone is ready to decompose, that will hasten it. I have not followed the researches of Professor Trowbridge, but on the side of prevailing winds, stone always decomposes most rapidly. Decomposition also takes place on the side most exposed to the sun, as the stone is then alternately wet and dry.

Theodore Cooper, M. Am. Soc. C. E.—They have removed from Trinity Church occasionally a stone, and they have redressed numbers of others. Now, what is the reason for that? It is the same kind of stone, is it not?

Prof. Egleston.—There are four different kinds of stone in Trinity Church. The contract was only for one, but it was not carried out. When the report of the cause of decay was made to the corporation, it was thought necessary to redress the stone previous to treating it. The decomposition has gone nearly into the interior of the stone, six inches in some cases, and it was found that some of the stones were so rotten that it was not worth while to redress them, and they were removed and new stones put in their place. It is true that stones when they are once dressed and have lost their quarry-water, and then redressed, will not stand as long as stones which are first dressed and then got their quarry hardening. Perhaps the most notable example of this is to be

seen in Paris, where the ordinary building stone is easily planed and sawed when first taken from the quarry; but if left long, the plane and the chisel are of little use, and they have to be cut as any other stone.

Oberlin Smith, M. Am. Soc. C. E.—I would like to know whether any experiments have been made by dissolving paraffine oils, which easily evaporate, and therefore get rid of the necessity of heat; and also whether there have been been any experiments with ordinary dust with the sand-blast instead of sand.

Prof. Egleston.—A large number of experiments have been made with paraffine and like compounds. They have had various results, according to the way the paraffine is applied. Some of them heat the stone in order to make the paraffine enter deeply into it. This is exceedingly dangerous when the stone has commenced to decompose, and is likely to increase rather than diminish the trouble, by causing expansion when the stone is already weak. When the stone is not heated the paraffine must be hot, and the application is best made in warm, dry weather. No substance known has the efficiency of paraffine. It is practically indestructible, and, if properly applied, it fills the pores and prevents any subsequent decomposition by the action of the weather. My intention, in studying the effect of abrasion, was to take ordinary flour, and my belief was that diamond could be worn away with ordinary flour; but since my first experiments were made, I have never found any one who would allow me to use the sand-blast sufficiently long to test it. I know that this statement seems incredible, but when the difference in hardness between ordinary sea-sand and the diamond is taken into account, and the fact is considered that with ordinary sea-sand the diamond has been worn away, it is quite credible that stone could be worn away with ordinary street dust, and much softer material. Street dust is much harder than the sand in the ordinary sand-blast. I have frequently made microscopic examinations of the ordinary street dust, and if any of you who live in New York will examine your window blinds after a rain storm, preceded by high wind, you will find them covered with minute particles of sharp quartz sand. There is also a considerable amount of iron filings besides organic dust. I believe firmly that if flour is hurled at stone with sufficiently great velocity, in a time easily named it will wear away the hardest of stone, or even the diamond.

Percival Roberts, M. Am. Soc. C. E.—I recollect a few years ago,

in connection with the electric light machines, that the comminutors, which were warranted not to wear away, were made with hard copper and the brushes with soft. It was found, however, that the comminutors wore away very fast. It was then reversed; the comminutors were made of soft copper and the brushes of hard, and the comminutors lasted much longer than before. It has also been found that the wear of hard steel rails is greater than the wear of soft steel rails. The fact seems to be that with hard and soft material in connection, the wear of the hard is greater than that of the soft.

Prof. Egleston.—I can explain Mr. Roberts' assertion. Any clockmaker sees these facts. The diamond saw is made of the softest copper that can be had. The fact of this wearing and cutting action can be seen in any old-fashioned clock escapement. The soft brass of which the escape wheel is made, frequently remains unacted on for 125 or 130 years, but the hard steel of the escapement is cut into so far as frequently to have the appearance of having been carefully filed. I recently made an examination of a clock of this kind, the escapement of which was deeply worn and the pinions of the escape wheel almost entirely cut through. The fact is that the soft material with the gummy oil holds the hard dust, as the copper of the diamond saw holds the diamond dust, and in this way grinds into the surface sometimes as far as one-sixteenth of an inch.

Frederick Brooks, M. Am. Soc. C. E.—I would like to inquire what was the intention in painting the stone of the Capitol at Washington?

Prof. Egleston.—I think the original intention was only to make the old part agree with the new in color, but the oil of the paint preserved the stone from the action of the air, and it has since been used for that purpose.

Mr. Flagg.—It was in such a bad condition that it was the only way to give it a respectable appearance.

Mendes Cohen, M. Am. Soc. C. E.—I have always heard that the first painting was done to the Capitol to restore the white surfaces that were destroyed with smoke in 1813.

Charles B. Brush, M. Am. Soc. C. E.—Does not this treatment shut up quarry-water in the stone, and is it not therefore injurious to the stone?

Prof. Egleston.—The quarry-water is very small in amount in the stone, and evaporates after an exposure of only a few months. The ex-

perience in the English Houses of Parliament was, that unless the stones were treated on their six faces, they would flake and chip, as if they had not been treated, in the course of a very short time. The only thing that has stood is sulphur. Applications made to the exterior of the stone did not answer except the sulphur. The stone treated with sulphur lasted 30 or 40 years and has only just begun to flake. Paraffine has, to my knowledge, never been used on the House of Commons. If any of the processes that require the stone to be heated were used on that building they would do great harm.

W. H. Bixby, M. Am. Soc. C. E.—I would like to know the effect of applying boiled linseed oil to marbles and other light materials?

Prof. Egleston.—It is not generally applied to marbles at all. Its object is to replace something dissolved out. It darkens stones.

Wm. P. Shinn, M. Am. Soc. C. E.—The Pittsburgh Court House, built in 1848, was built of Freeport sandstone. The columns, which were doric, I think, were painted immediately after they were erected. The result was a scaling of one-eighth to three-sixteenths of an inch off the whole surface of the columns, leaving them rough. I was not in Pittsburgh at the time the painting was done. The first time I saw the Court House was some five or six years afterwards. The stone-mason who erected it was a contractor under me in the construction of the Fort Wayne road, and stated, as his opinion, that the cause of the scaling was that the paint was put on before the evaporation of the quarry-water. I do not know as to his theory being correct, but I do know as to the scaling, and that the paint was put on immediately after the erection of the stone.

Mr. Becker.—This stone is found in the neighborhood of Pittsburgh. It is a soft, oleaginous sandstone, and, while wearing but slowly, it soon shows unmistakable signs of decay from water and the elements. But that stone contains so large an amount of quarry-water that it is impossible to use it fresh from the quarry. The stone has to be seasoned from four to six months. If the stone is laid into the work direct from the quarry it will crack from frost, and I should think that stone containing such a large amount of water should have some treatment to eliminate that moisture before the remedy against decay is applied.

Prof. Egleston.—It certainly should. That amount is unusual.

Mr. Becker.—Then there is another sandstone on the Ohio River, above Cincinnati, which is so largely charged with coal-tar that I have

frequently seen it drop down in large drops, so as to disfigure the whole face of the stone. For a season or two it actually runs down the face of the stone. Now how would that have to be treated?

Prof. EGLESTON.—I should not think such a stone as that needed any treatment at all. It is already treated. If such a stone is examined with a microscope, it would be found full of petroleum, and its compounds, which are the most serviceable materials to fill the cavities made by the solution of the binding material.

Mr. BECKER.—We have that stone in such large quantities that it constitutes almost the only available material for many railroad purposes in that vicinity. We are using it, with the precaution of seasoning it always for several months before we attempt to put it in a building.

Prof. EGLESTON.—I should think such a stone as that would certainly have to be seasoned. Does that stone decompose?

Mr. BECKER.—It decomposes from the surface, but so slightly that it would not be injurious in rough structures, such as railroad bridges.

Prof. EGLESTON.—It would be impossible to tell how to treat it without making a very careful examination to begin with.

WALTER KATTE, M. Am. Soc. C. E.—Have you had occasion to note or make mechanical or chemical experiments upon brick, terra cotta or beton?

Prof. EGLESTON.—Beton is artificial stone. Brick is very largely porous, and the stains which come upon bricks at the present time are entirely preventible. These stains are the result of a cheap method of making the lime and cement which are now used. Good brick and terra-cotta need no protection, but coating them would prevent the stains by preventing the percolation of the water.

Mr. FLAGG.—Will Professor Egleston explain how it is, that since carbonic acid is united chemically with the lime in limestone, the lime can be attacked and disintegrated by water containing the same acid?

Prof. EGLESTON.—All carbonates are more or less soluble in an excess of carbonic acid, and they are easily soluble provided the solution is dilute. When very concentrated they do not dissolve so easily. When limestone and dolomite occur together, one or the other of the two is apt to be in larger crystals. In the case of the marble altar tombstone in Trinity churchyard, the dolomite crystals are very large. The calcite is in small amount. The tombstone was originally polished, but all the calcite has been dissolved out, leaving dolomite crystals protruding, and

so rough that the slab looks as if it had never been polished. In the case of the stone from the quarries in Lee, Mass., of which the Capitol at Washington is built, the dolomite and limestone are together in crystals of about equal size. The stone in the quarry is filled with crystals of tremolite, which is a silicate of lime and magnesia, which is not attacked. Where the quarry stone is exposed to the weather for a long time, the lime has been entirely dissolved out, leaving the dolomite as a sand through which the tremolite crystals are scattered entirely detached.

T. H. Johnson, M. Am. Soc. C. E.—During my connection with the building of the Indiana State House we used large quantities of oolitic limestone, some of which was dressed by hand and some by machinery. In both cases it was found that the action of the tool left a thin skin of injured surface, which the first winter's exposure would remove. I found also that the stone-cutters use the word "stunned" to designate this injured surface. All workmen engaged in polishing marble, granite, and other stones susceptible of polish, recognize this effect of the tool, and know a good polish is impossible until the whole depth of the "stunned material" has been rubbed down.

Mr. Flagg.—This skin that comes off, does it apply to the machine-dressed or the hand-dressed, or to both?

Mr. Johnson.—To both. In this connection I would also state that I made a series of tests upon the transverse strength and modulus of elasticity of various building stones. Among the samples tested were a large number of oolitic limestones, some of which had been dressed by hand and some had been sawed. I found in all cases that both the strength and elasticity had been impaired by the tool dressing, so that the modulus of transverse rupture and the modulus of elasticity were both reduced to two-thirds of the corresponding moduli of sawed samples.

Mr. Collingwood.—That would seem to show that the results in our text books, which have been produced by very finely dressed specimens, must be very inaccurate if they are only two-thirds of the strength they really possess, when there is no injury to the surface.

Mr. Croes.—I regret to say that I do not thoroughly understand yet the distinction between theory and practice as given by Professor Egleston. These stones which have been preserved by various methods, or which have not been preserved at all, and which have shown disintegration, are stones, as I understand, that have been laid in walls for a long

period of time. I may be mistaken, but I have not understood that stones which have been saturated on all sides with such a preparation as the Professor recommends have been tested for any length of time, have been laid up in a wall, and have proven that they will not deteriorate. The processes of preservation that have been applied have been applied to the faces of walls, and have either failed or succeeded, as the case may be, in the instances mentioned. Now, if I am correct in this supposition, that this process of saturation of the stone or impregnation of the stone with an oleaginous substance has not been tested in masonry, I cannot understand how a good bond can be procured in masonry, in which the mortar mixed with water is brought in contact with the oily surface of the stone. I do not believe that it will take a good bond in the absence of evidence to the contrary.

Prof. Egleston.—I thought I had made that plain. I intended to state it, that the only successful experiments on the Houses of Parliament were those in which a preserving material had been applied to the whole surface of the stone, that is all the surface of each of the six sides. The only exception was of those treated with sulphur. Stones have stood for 20 years, the surface of which only was impregnated with sulphur, but these have just commenced to chip in July last. Every other stone that was put into the Houses of Parliament that has not been treated on all its surfaces, has failed. Those treated on all their surfaces have not failed.

Mr. Croes.—Have those stones been treated with oil?

Prof. Egleston.—They have been treated with oil and substances of that character.

Mr. Croes.—I understood that the stones were treated with sulphur.

Prof. Egleston.—That was only on the outside of a portion of one of the buildings, and was done about twenty years ago.

Mr. Johnson.—We have in Ohio a variety of sandstone which is more or less impregnated with saltpetre. What would be the effect of the combination of oil with saltpetre?

Prof. Egleston.—I do not know, never having tried it, but I think the effect would be that the oil would be decomposed, as the saltpetre would come out on the surface. So far as my experience goes, the only thing that can be done to preserve stone is to prevent the action of atmospheric influences, those that go from the outside in. If there is anything in the stone to come out it has got to come out. I do not

know of any method of preserving stone except to prevent the influence of the atmosphere working from the outside in. Of course it would be quite possible to preserve the stone by taking all the saltpetre out, but it would not be practicable; it would be too expensive.

D. J. Whittemore, M. Am. Soc. C. E.—This impregnating of stone with oils or things of that nature I think is nothing new. I think that Vitruvius, or some of the ancient writers, describes processes for the manufacture of cement by which there was introduced hog's lard or olive oil, and the mortar was used principally for the purpose of lining the aqueducts; and, judging from a specimen of the mortar, it bears out conclusively that such matter was used, as the oily substance has vanished, and it is porous now, more open probably than the ordinary brick. Such substances might, in my opinion, have a temporary effect towards preventing disintegration. As to permanent effect, I think the question is yet to be solved.

F. G. Darlington, Jun. Am. Soc. C. E.—I do not know whether there are any data to show the cost of the application of any of the preservatives to any of the stone, and the question arises whether it would not be cheaper in the first place to pick a stone that would stand the atmospheric influences rather than to take a stone that would not and treat it with substances to preserve it.

Prof. Egleston.—There is no question about that. As the stones come from the same quarry, the cheapest and best way is to pick the stone that will stand and reject absolutely every stone that will not stand, and if that was done no sandstones would be used except those having a siliceous binding. It is moreover quite possible to fill the pores of a stone, whether they were in the stone in the quarry or have been formed by atmospheric influences, by sulphur or paraffine, which will not decompose. Oil is a palliative and arrests decomposition temporarily, but when the gum which it forms is decomposed, the coating must be repeated or the action will commence again.

Mr. Brush.—If I understand the Professor, the treatment he proposes, that is, oil on the outside of the stone, does not prevent moisture leaving it. If that is a fact, it relieves my mind from the embarrassment of the possibility of confining the moisture in the stone.

Prof. Egleston.—I did not say moisture. The nitre is nitrate of potash or nitrate of soda. The ordinary nitrate of commerce is nitrate of potash, and there is no power that will prevent its coming out if the

materials that form it are in the stone itself. The nitrates, when they exude, will form a soap with the oil, which will be washed away.

Mr. Brush.—It seems to me very undesirable to do anything to stone that would be the same as painting would be to wood. If you confine the moisture it would have a serious effect, and severe cold would break the stone.

Mr. Darlington.—I would like to know what would be the effect of extreme heat upon stone treated with any of those preservatives. If with linseed oil, would not the heat of our extreme summers have the effect of bringing the oil all out ?

Prof. Egleston.—So far as any experiments have been made, I think it is exactly the contrary. The higher the heat the further the oil penetrates the stone. Experiments have been made up to about 250 degrees; not much higher than that, because a higher heat would injure the stone, but the penetration is greater as the heat upon the stone is higher. Small pieces of stone can be treated in the laboratory to this temperature, or even above it, without much danger. When large pieces are treated on the surface by means of flame thrown on it, the heat must of necessity be applied over moist surfaces, and the danger of damage will always be very great. When the stone is heated by the sun, the temperature will often be very high without danger to the stone, and as the heat has penetrated under such circumstances to a considerable depth, the penetration will be greater than is possible by artificial means, especially in buildings.

C. J. H. Woodbury, M. Am. Soc. C. E.—I have had some experience in the protection of a brick building by the use of a plaster composed of boiled linseed oil mixed with sand colored with red lead, the color after drying being similar to the Portland sandstone. A coat of boiled linseed oil was laid upon the brick wall before the mixture was applied. A covering of this material upon a building has resisted the weather for three years without any chipping, cracking, spotting or disintegration of any kind.

Reference was made in the paper to the slates formerly used as grave-stones throughout New England. There is quite a difference in the ability of the product of various quarries to resist the weather.

A number of years ago there was a slate quarry in the southern portion of New Hampshire which was held in great reputation for its headstones, which would wear as smooth as glass upon exposure to the

weather, while the production of other slate quarries would wear rough, although slowly.

The oldest headstone in this country, as far as I have any means of knowing, is in the Western burying ground at Lynn, Mass., and dates back to 1628. It is still smooth and perfectly legible. It may be an act of vandalism, but some of these ancient headstones, which have attested their quality through many years, have been appropriated, redressed, and used as tablets in more pretentious monuments of later date.

Mr. Croes.—I saw a statement in one of the New York papers a few months ago to the effect that the surface of the obelisk in Central Park was disintegrating from the effects of this climate.

Prof. Egleston.—That is true, and the disintegration is very rapid, but from a different cause altogether. That stone has been exposed for two thousand years to a dry climate at a high temperature, and the disintegration of the granite had already commenced before it came here. It had probably stood for two thousand years, and would probably have disintegrated in two thousand years more; but it has been brought to the very worst climate in the world, I suppose, except Boston, and now any one who goes there after a storm can pick up as many pieces as he pleases, and can get relics very easily. I have very little hesitation in saying that if the obelisk is not placed under some dome, the dome of the Museum of Art, as it should have been in the first place, in twenty or thirty years it will probably be beyond repair.

Mr. Croes.—How large pieces are coming off?

Prof. Egleston.—From the size of a pea to pieces several inches long.

Mr. Croes.—On which side of the obelisk?

Prof. Egleston.—In all directions. It does not seem to be from one side more than another. In regard to the slates of which Mr. Woodbury speaks, I have had the same experience in roofing. The roof of my country place twenty years ago was covered with the best slate I could get from the Canaan quarry. I examined that slate lately and found some of it no better than clay. Some of it had all gone to pieces so that you could crumble it in your fingers. I have not completed my investigation in regard to the causes of the disintegration of slate. I simply wish to call the attention of engineers to the fact that water-proofing alone will arrest the process of decomposition.

Captain Bixby.—The effect of the atmosphere upon granite and other stones is shown very clearly also on iron at Fort Macon, North Carolina. The fort is of old-style masonry, inside of brick. Many of those bricks that come out to the face of the wall as headers are so soft that you can stick in a lead pencil almost anywhere and take out half an inch of the brick. The iron balustrade going up the side of the steps to the upper parade on the side where the southeast winds can strike it has wasted away under that wind, so that iron bars one inch square in a vertical position have been completely rusted through. Some of them are standing there now in that way. The middle part of the bar is gone, and you can see the evidence of rust and the corroding action of the atmosphere to show that that is the way the bars have disappeared, and not from any other cause.

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NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

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REPORT OF PROGRESS BY THE COMMITTEE ON THE COMPRESSIVE STRENGTH OF CEMENTS AND THE COMPRESSION OF CEMENTS AND SETTLEMENT OF MASONRY.

PRESENTED AT THE ANNUAL CONVENTION AT DENVER, COLO., JULY 5TH, 1886.

Your Committee beg leave to submit the following as a report of progress in their work. For various reasons, unnecessary to enumerate, the work thus far done has been only that of accurate study of previous investigations, and a discussion between the Members as to apparatus and methods, which it is hoped will bear fruit in the future.

As some interesting results have been obtained by other experimenters, the Committee deem it desirable to give a summary of some of them, as they have not been brought prominently to notice heretofore.

In a pamphlet issued by the "Commissioners for the Erection of the Public Buildings" in Philadelphia (J. J. McArthur, Jr., architect), is given a series of experiments at the Watertown Arsenal on building-stones, cast and wrought-iron, bricks and brick piers set in cement-mortars.

As to the specimens of stone tested, the compression is not given; they were all in 6-inch cubes. We give the summary of results, since they

tend to show that large specimens give greater proportionate strength than smaller ones, the results being higher then ordinary.

TABLE No. 1.

From pamphlet of "Mechanical Tests of Building Material made at the Watertown Arsenal by the United States Ordnance Department at the request of the Commissioners for the Erection of the Philadelphia Public Buildings, John McArthur, Jr., Architect."

Marble.

Locality.	Color.	Direction of Pressure.	Total Load Applied.	Crushing Force on a Square Inch, in lbs. Avoirdupois.	Sectional area, in Square Inches.	Remarks.	Register Number of Experiment.
Lee, Mass	Blue	End	715 000	20 504	34.87	Burst into fragments	2550
"	White	Bed	800 000	22 370	35.16	Slight flaking on one face	2551
"	W. & B.	End	800 000	22 860	34.99	Without apparent injury	2565
"	White	"	800 000	22 820	35.05	" "	2566
"	Blue	Bed	800 000	22 900	34.93	Flaked off along one edge	2567
"	W. & B.	"	767 000	21 700	35.34	Crushed suddenly	2568
Montgomery Co. Pa.	Blue	"	466 300	11 470	40.64	Failed suddenly	2552
"	"	End	400 000	10 420	38.40	"	2554
"	"	Bed	543 000	13 700	39.63	Ultimate strength	2569
"	"	End	398 000	10 120	39.33	"	2570
"	"	"	347 500	9 590	36.24	"	2571
"	"	Bed	434 000	10 940	39.67	"	2572

Limestone.

Conshohocken, Pa.		End	494 000	14 090	35.05	Ultimate strength	2557
"		Bed	566 000	16 340	34.63	"	2558
Indiana		End	377 000	8 530	44.22	"	2575
"		"	320 500	7 190	44.56	"	2576
"		Bed	321 000	7 776	41.38	"	2577
"		"	438 300	10 620	41.28	"	2578

Dove-colored Marble.

Vermont		Bed	531 200	13 400	39.65	Ultimate strength	2579
"		End	379 800	9 870	38.48	"	2580

Sandstone.

Hummelstown, Pa.		Bed	528 700	12 810	41.28	Ultimate strength	2555
"		End	570 300	13 610	41.92	"	2556
Ohio	Buff	Bed	256 000	6 510	39.32	"	2563
"	"	End	199 500	4 860	41.02	"	2564
"	"	Bed	289 500	7 020	41.25	"	2573
"	"	End	160 000	3 940	40.06	Bearings imperfect	2574
"	Blue	"	305 000	7 680	39.68	Ultimate strength	2581
"	"	Bed	435 400	10 400	41.90	"	2582
"	"	End	391 800	9 795	40.00	"	2583
"	"	Bed	351 000	8 710	40.30	"	2584
"	"	End	672 100	16 280	41.28	Fractured suddenly with loud report.	2585
"	"	Bed	493 500	12 420	39.74	Ultimate strength	2586

Brick.

Manufacturer.	Quality.	Make.	Total Load Applied.	Crushing Force, in Pounds per Square Inch.	Area of Sample Inches.	Remarks.	Number of Experiment.
Dobbins	Hard	Machine	288 500	8 610	33.50	Failure gradually took place	2559
"	"	"	411 000	11 720	35.07	Failed rapidly near close of test	2587
"	"	"	304 000	9 210	33.00	Ultimate strength	2588
Excelsior	"	"	261 000	8 310	31.39	Failed by breaking up	2560
"	"	"	180 200	5 540	32.53	Ultimate strength	2589
"	"	"	188 100	5 790	32.51	"	2590
J. R. Huhn	"	Hand	591 000	18 690	31.63	Failed suddenly at very end of test	2561
"	"	"	346 400	10 970	31.57	Ultimate strength	2591
"	"	"	654 000	20 830	31.4	"	2592
"	"	"	364 000	11 150	32.64	"	2593
"	"	"	382 000	11 650	32.8	"	2594
Dotterer	Pressed	Machine	256 500	7 770	33.03	"	2562
"	"	"	304 000	9 050	33.6	"	2595
"	"	"	243 000	7 210	33.70	"	2596

Cast-iron.

Form of Specimen.	Diameter.	Length.	Total Load Applied.	Crushing Force, in Pounds per Square Inch.	Area of Sample in Inches.	Remarks.	Number of Experiment.
Solid cylinder	3"	5".998	501 000	60 360	8.3	Oblique fracture. Sides swelled	2597
Open cylinder	4".41	6".001	566 000	68 190	8.3	Sides swelled	2598
"	8".78	5".998	657 600	79 230	8.3	Fractured into twenty-five pieces	2599

Wrought-iron.

Form of Specimen.	Height.	Length.	Total Load Applied.	Crushing Force, in Pounds per Square Inch.	Area of Sample in Inches.	Remarks.	Number of Experiment.
Rolled I-beam	7".05	6".004	282 000	54 230	5.2	Flanges buckled outwards	2600
"	9".00	6".000	353 000	54 310	6.5	" "	2601
"	15".25	6".002	800 000	53 330	15.	Web and flanges buckled	2602

Three of the tests of marble from Lee were with the grain, and three across the grain, but there was no appreciable difference in strength.

Of the marble from Montgomery County, Pa., the strength was greatest when on the bed.

Of limestone from Conshohocken, Pa., the strength on bed was 16 340, and on end 14 090 pounds.

Limestone from Indiana gave on end 7 190 to 8 530 pounds, and on bed 7 776 to 10 620 pounds.

Vermont dove-colored marble gave on end 9 870, and on bed 13 400 pounds.

Sandstone from Hummelstown, Pa., 12 810 on bed and 13 610 on end.

Sandstones from Ohio, 5 specimens on end gave an average of 8 711, varying from 3 940 to 16 280 pounds, and 5 on bed gave 9 012 pounds, varying from 6 510 to 12 400 pounds. Some of the specimens began failing at 1 000 to 1 500 pounds less.

Of bricks, hard-burned, machine-made Philadelphia bricks crushed at (in full size) 5 540 pounds to 11 720 pounds per square inch, the average of six being 8 197 pounds, and the lowest pressure at which there was any sign of failure was about 3 000 pounds.

Of machine-made pressed Philadelphia brick, the strengths were 7 200 to 9 050 pounds per square inch, the average of three being 8 010 pounds, and the lowest pressure at first failure 2 500 pounds.

Of hand-made Philadelphia bricks the strengths were 10 970 pounds to 20 830 pounds per square inch, the average of five being 14 658, and the lowest pressure at which failure began 3 000 pounds, all others being much higher, 6 300 pounds and over.

A solid cylinder of cast-iron 3 inches in diameter and 6 inches long, crushed at 60 360 pounds per square inch. Hollow cylinders of same length and area of section, 4½ inches in diameter, failed at 68 190 pounds, and 8¾ inches diameter at 79 230 pounds, the limit of elasticity being at about 15 000 pounds.

Rolled I beams 7 to 15 inches, in 6-inch lengths, failed by buckling at about 54 000 pounds, with elastic limit in one case of 10 000 pounds, but yet not increasing perceptibly up to 28 000, and in the others of about 30 000.

In none of the experiments thus far mentioned is the change of dimensions under compression given.

The remainder of the experiments were on brick piers, five bricks high and one and a half bricks square, thoroughly bonded, and laid in cement or lime-mortar.

The cement-mortar consisted of "1 part Rosedale cement (Valley brand) to 2 parts sharp bar sand." The lime-mortar of 1 part "Cedar Hollow" lime, from Chester County, Pa., to 4 parts of same sand. The piers were all a week short of 15 months' old, and set in the air. The following table gives a summary of results.

TABLE No. 2.—GENERAL ABSTRACT.

Official No. of Test.	Maker of Bricks.	Mortar.	Area in Square Inches.	Snapping Sounds.	Per Square Inch.	Cracked.	Per Square Inch.	Total Compression at 50 000 lbs. on Specimen.	Set at 50 000 lbs. on Specimen.	Pounds per square inch at 50 000 on Specimen.	Ultimate Strength.	Per Square Inch.
3255	Dobbins	Lime	165.75	85 000	512	110 000	663	.0220	.0130	302	239 000	1 442
3256	"	"	162.56	150 000	922	150 000	922	.0180	.0100	308	259 100	1 594
3257	"	Cement	169.00	142 000	840	180 000	1 065	.0180	.0090	296	356 900	2 112
3258	"	"	162.56	300 000	1 845	300 000	1 845	.0150	.0075	308	420 000	2 584
3259	Huhn	Lime	156.25	78 000	499	160 000	1 824	.0210	.0110	320	299 000	1 914
3260	"	Cement	159.38	320 000	2 070	320 000	2 070	.0150	.0070	320	428 000	2 685
3261	Dotterer	"	156.25	.....	....	150 000	960	.0210	.0080	320	250 000	1 600
3262	"	Lime	156.25	.....	....	120 000	768	.0165	.0070	320	182 400	1 167
3263	Excelsior	Cement	162.56	.....	....	240 000	1 476	.0160	.0075	308	268 900	1 654
3264	"	"	159.38	100 000	627	220 000	1 380	.0140	.0065	314	266 500	1 672
3265	"	Lime	158.76	.....	....	160 000	1 070	.0240	.0130	315	178 800	1 126
3266	"	"	156.25	.....	....	100 000	640	.0280	.0165	320	124 900	699

Abstract of Average Strengths.

In Lime-mortar. *First crack*..... 864.23 pounds square inch, or 62.226 tons square foot.
" Cement " " ..... 1 567.56 " " 112.864 " "

In Lime-mortar. *Ultimate strength*.... 1 375 pounds square inch, or 99 tons square foot.
" Cement- " " .... 2 141.4 " " 154.18 " "

John McArthur, Jr.,
Architect.

From this, and the more detailed results given in the pamphlet, we deduce the following statement:

Of the six piers set in lime-mortar, the first snapping sounds were heard with a pressure on specimens of 499 to 1 070 pounds per square inch, the average of all being 735 pounds.

The first perceptible crack occurred with 848 pounds average pressure, and the average crushing strength was 1 360 pounds.

The first perceptible permanent set was measured at 302 to 320 pounds pressure, this being 50 000 pounds on specimen, at which time the total compression was 0.0165 to 0.0280 inch on 12¾ inches, or an average on all of 0.0216 inch, giving a co-efficient of compression of 0.00054 per 100 pounds of applied weight. The compression continued quite uniform up to the time when the first snapping sounds were heard, at which time the average of all gave a coefficient slightly less, or 0.000495 per 100 pounds, after which it increased.

Of the six piers set in cement, the first permanent set was at 296 to 320 pounds, with an average of 311 pounds. The total compression under this pressure was from 0.0150 inch to 0.0230 inch, with an average of 0.0178 inch and an average coefficient of 0.00045. The first snapping sounds were heard at 627 to 1 845 pounds, with an average of 1 300 pounds, and an average coefficient of compression of 0.0003.

Since the compression is in all cases greatest under the initial load, it is reasonable to conclude that the joints compress at first more than the bricks. This is also shown by the greater amount of compression of the specimens set in lime-mortar.

The first perceptible crack occurred under loads from 960 to 2 070 pounds, with an average of 1 466 pounds per square inch.

Professor Swain and Captain Maclay, of the Committee, have both made translations from the German of some interesting results obtained by Professor Bauschinger, of Munich. These were published in the "Mittheilungen aus dem Mechanisch-Technischen Laboratorium, der Kœnigl. technischen Hochschule in Munchen." (Heft. VII.)

The tests made included those for tension, compression, shearing, flexure, adhesion, behavior during setting, etc. They were made on seven different brands of Portland cement (six German and one French).

For behavior during setting glass cylinders $2\frac{8}{10}$ inches high, $2\frac{2}{10}$ inches in diameter were used, but it is not stated whether the setting occurred in air or water—probably the former. The results reached differed widely from those of Mr. Eliot C. Clarke, M. Am. Soc. C. E., who determined that all cement setting in water expanded slowly for about two weeks (see Transactions Am. Soc. C. E., 1885, pp. 167–8). Professor Bauschinger found that out of 28 different mixtures, in the case of only 7 were all the glasses broken even after 80 days, while with 3 no glasses

were broken, and with 6 only 1. In 11 cases a glass was broken after 60 days, and at the end of 80 days 60 out of 132 remained unbroken. As these results are not quantitative as to expansion, they are too indefinite to be of much value.

Fig. 1.

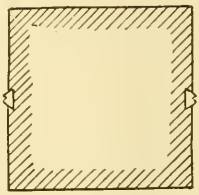


Fig. 2, page 725, shows the apparatus designed for measuring the changes of dimension occurring as hardening progresses; the first measurement being made 48 hours after moulding the specimen, or 24 hours after the insertion of the small metal pieces (see Fig. 1) having conical depressions, between which all measurements were taken.

The measuring apparatus consists of a U-shaped piece *AA*, having in one arm a thread cut for the insertion of a micrometer screw. On the screw is the wheel *B*, $\frac{1}{100}$ of a revolution of which can be read directly and $\frac{1}{1000}$ easily estimated. On the other arm of *AA* is a multiplying lever *DD*, whose shorter (lower) arm rests in one of the conical cavities in the specimen, while the longer arm traverses the scale *F* on the frame-like extension upward of the piece *AA*. The spring *E* attached to this frame, keeps the lever in contact with the specimen. The steel joint of the micrometer screw is in contact with the other end of the specimen.

To prevent any possibility of pressure other than a definite strain of contact, the whole weight of the U and attachments is balanced about the pivot *a* by the adjusting weight *G*, and the whole weight on the pivot *a* is suspended by the rod *H* from the lever *J*, bearing a second adjusting weight, *K*. The rod *H* has ball and socket joints at both ends. It will be seen that by turning the micrometer screw until the index is in the center of the scale *F*, and making proper allowances for the differences in temperature between the apparatus and the specimen, and also for changes in temperature as the experiments are made (since brass and cement expand differently), the exact changes of length can be determined.

The humidity of the air was found to exert no effect upon the specimen, but specimens immersed in water changed much more than those kept in air.

Five specimens were made of each kind and each mixture of cement, being cubes of $4\frac{72}{100}$ inches on a side; 3 of these were allowed to harden

TABLE No. 3.

Increase or decrease of the side of a cube measuring originally 12 centimeters (4.72 inches), given in thousandths ($\frac{1}{1000}$) of a millimeter from second day after mixing up to 16 weeks. + denotes increase. — denotes decrease.

Mark of Cement.	Proportion of Materials Used.		Weight of Sand and proportion of Water in it.	Amount of Water used in mixing Mortars in Liters, and percentages.	4 days in		1 week in		2 weeks in		4 weeks in		6 weeks in		8 weeks in		16 weeks in	
	Cement in Liters.	Sand in Liters.			Air.	Water.	Air.	Water.	Air.	Water.	Air.	Water.	Air.	Water.	Air.	Water.	Air.	Water.
				Liters. Per cent.														
A	1	0	The sand weighed 1.217 kilo. per liter, and contained 5.55 per cent. water.	0.276 = 20.8	— 1	....	+ 2	+16	— 3	+22	— 29	+ 27	— 55	+ 36	— 69	+ 23	—164	+ 44
	1	3		0.370 = 27 8	— 3	— 3	— 7	— 1	— 8	— 1	— 49	— 6	— 80	+ 10	—100	— 8	—160	+ 1
	1	5		0.460 = 34.6	0	— 1	— 3	— 6	—11	— 6	— 51	— 19	— 70	— 16	— 86	— 31	—117	— 32
B	1	0	1.245 kilo. with 4.68 per cent. water.	0.300 = 2.32	+10	+15	+15	+34	+ 3	+89	— 16	+113	— 49	+131	— 74	+144	—206	+184
	1	3		0.370 = 28.7	+ 2	+ 3	+ 7	+ 8	— 4	+ 8	— 48	+ 16	— 66	+ 12	— 77	+ 19	—126	+ 24
	1	5		0.410 = 35.6	— 1	+ 4	+ 4	+17	—11	+14	— 57	+ 14	— 65	+ 14	— 68	+ 21	—111	+ 27
C	1	0	1 252 kilo with 4.95 per cent. water.	0.244 = 18.5	+ 7	+13	+ 7	+17	—11	+35	— 39	+ 38	— 57	+ 30	— 80	+ 46	—148	+ 55
	1	3		0.360 = 27.2	+ 3	+ 5	— 4	—30	—13	+ 2	— 43	+ 3	— 69	— 10	— 81	+ 5	—135	+ 10
	1	5		0.410 = 31.0	+ 5	+ 5	— 7	+ 4	—24	+ 8	— 52	+ 6	— 72	— 9	— 89	+ 2	—126	— 2
D	1	0	1.269 kilo. with 4.73 per cent. water.	0.234 = 19.4	— 5	+ 8	+14	+16	—42	+16	— 51	+ 22	— 73	+ 32	—105	+ 32	—222	+ 43
	1	3		0 340 = 28.1	+ 1	— 1	+ 1	— 3	— 8	— 5	— 40	— 11	— 61	+ 1	— 91	— 1	—124	+ 2
	1	5		0.400 = 33.1	— 1	— 1	—12	+ 9	—46	+ 2	— 82	— 1	—102	+ 8	—127	+ 4	—154	+ 3
E	1	0	1.253 kilo. with 5.55 per cent. water.	0.302 = 23.9	— 7	+13	—51	+32	—93	+38	—180	+ 15	—232	+ 25	.....	.....	—407	+ 23
	1	3		0.390 = 30 8	+ 3	+14	—15	0	—25	+ 6	— 79	— 8	— 93	+ 4	.....	.....	—157	— 3
	1	5		0.490 = 38.7	— 2	+13	—15	+ 2	—27	+ 7	— 66	— 11	— 97	+ 6	.....	.....	—164	— 4
F	1	0	1.251 kilo. with 5.31 per cent. water.	0.270 = 21.4	—13	+ 5	—27	+13	—54	+11	— 76	+ 21	.....	.....	—115	+ 15	+164	+ 26
	1	3		0.350 = 27.7	— 7	— 1	—13	+ 8	—41	0	— 62	+ 3	.....	.....	—110	+ 2	—144	+ 12
	1	5		0.450 = 33.2	— 9	+ 3	—25	—11	—52	0	— 82	+ 12	.....	.....	—127	0	—166	+ 7
G	1	0	1.283 kilo. with 5.80 per cent. water.	0 300 = 22.9	—23	— 3	—31	+ 4	—55	+ 7	— 76	+ 24	.....	.....	—155	+ 31	—288	+ 15
	1	3		0.400 = 30.6	—10	— 6	—28	— 6	—59	+ 5	— 85	+ 4	.....	.....	—131	+ 14	—177	— 2
	1	5		0.480 = 36.7	— 5	— 8	—14	— 1	—37	+ 9	— 64	+ 4	.....	.....	—103	+ 2	—131	— 9
H	1	0	1.287 kilo. with 5,57 per cent, water.	0.250 = 19.6	—13	+ 7	—35	+ 2	—44	+13	— 73	+ 10	.....	.....	—148	+ 28	—257	+ 30
	1	3		0.350 = 27.5	— 1	+10	—16	+ 9	—17	+15	— 57	+ 11	.....	.....	—107	+ 20	—145	+ 11
	1	5		0.430 = 33.7	+ 3	+ 7	—12	+ 3	—22	+11	— 51	+ 7	.....	.....	—101	+ 14	—126	0
R	1	0	1.276 kilo. with 5.41 per cent. water.	0.245 = 19.8	—18	+ 3	—14	+16	—40	+23	— 56	+ 23	.....	.....	—128	+ 18	—203	+ 23
	1	3		0.330 = 27.6	— 6	+ 1	+ 7	+23	— 5	+21	— 25	+ 29	.....	.....	— 67	+ 30	—101	+ 27
	1	5		0.120 = 33.9	— 6	— 1	+ 3	+14	— 5	+19	— 24	+ 21	.....	.....	— 73	+ 18	— 97	+ 16

in air and 2 in water, and measurements were made at intervals, with the results shown in Table No. 3.

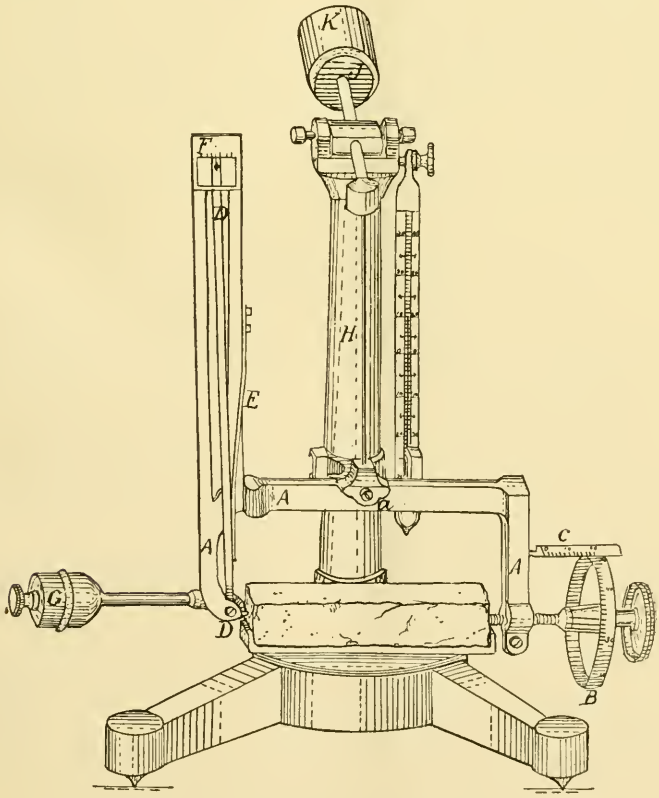
It will be seen that the amount of water contained in the sand was in every case noted, as well as the water added in making the mortar.

The results may be summarized thus:

First.—In case of all three proportions of cement and sand, the specimens hardening in air show a progressive contraction with age, sometimes with a very slight preliminary expansion up to an age of about one week.

Second.—The total effect at the end of sixteen weeks, with mortars hardening in air, is in every case a contraction.

Fig. 2.



Third.—This total contraction is generally greatest with neat cement, and it decreases as the proportion of sand is increased. In a number of cases, however, the adding of sand appears to accelerate the contraction during the first four weeks, making it greater as the proportion of sand is increased.

Fourth.—The total contraction after sixteen weeks, for mortars hardening in air, varies as follows:

1	of cement	to	0	of sand	from	.148 mm.	to	.174 mm.	or from	0.12 to 0.34	of 1 per cent.
1	"	"	3	"	"	.101 mm.	to	.177 mm.	"	0.08 to 0.15	" "
1	"	"	5	"	"	.097 mm.	to	.166 mm.	"	0.08 to 0.14	" "

Fifth.—With cement hardening under water, the phenomena are much more irregular. In general there is a continued expansion, but in a few cases at the end of sixteen weeks it was practically nothing.

Sixth.—The expansion under water is in every case greatest and most regular with neat cement, increasing progressively with age. As the amount of sand is increased, the expansion diminishes and becomes irregular.

Seventh.—The total expansion of cement hardening under water is as follows:

1	of cement	to	0	of sand	from	0.15 mm.	to	0.184 mm.	or from	0.01 to 0.15	of 1 per cent.
1	"	"	3	"	"	—0.003 mm.	to	0.027 mm.	"	0.0 to 0.02	" "
1	"	"	5	"	"	—0.032 mm.	to	0.027 mm.	"	—0.03 to 0.02	" "

The fact that there is an expansion in water and a contraction in air may account for the discrepancies between Mr. Clarke's and Professor Bauschinger's experiments. Mr. Clarke gave the expansion on a 10-inch cube as one-tenth of one per cent.

In Volume LXII, page 108, of Proceedings of the Institution of Civil Engineers, in a paper by Mr. John Grant, is a table of experiments on prisms, 4 inches long and 2 inches square, hardening in water for various periods, from one week to twelve months. (Table No. 4.)

The table gives the results, from which the author draws the following conclusions:

1. All cements expand more or less when hardening under water.

2. The expansion of good cement is so very slight, that in practice it need hardly be taken into consideration.

3. The expansion is greatest when the increase of strength is most active.

4. It diminishes in proportion to the admixture of sand.

TABLE No. 4.

Showing the Amount of Expansion in Twelve Varieties of Cement, Neat, and Mixed with Three Parts of Sand.—(From Min. Proc. Inst. C. E., Vol. LXII, p. 170.)

Sort of Cement.	Residue on sieve of 900 meshes sq. ctm. = 5.806 per sq. in.	Time of setting minutes.	A prism of 10 centimeters = 3.9708 inches in length and 5 centimeters square, lying in water, expands (millimeters)														REMARKS.
			Neat Cement.							Three of Standard Sand.							
			One week.	From one to four weeks.	From one to three months.	From three to six months.	From six to nine months.	From nine to twelve months.	Total.	One week.	From one to four weeks.	From one to three months.	From three to six months.	From six to nine months.	From nine to twelve months.	Total.	
A	5.0	240	0.0254	0.0228	0.0233	0.0067	0.0184	0.0100	0.1066	.....	.....	.....	.....	.....	.....	.....	
B	8.5	30	0.0471	0.0198	0.0140	0.0135	0.0186	0.0097	0.1227	0.0134	0.0040	0.0003	0.0050	0.0033	0.0057	0.0317	
C	7.5	660	0.0141	0.0148	0.0081	0.0177	0.0107	0.0048	0.0702	0.0073	0.0013	0.0007	0.0000	0.0007	0.0000	0.0100	
D	10.7	35	0.0467	0.0450	0.0217	0.0341	0.0260	0.0132	0.1867	0.0172	0.0023	0.0006	0.0038	0.0033	0.0044	0.0316	
E	12.5	540	0.1217	0.0322	0.0173	0.0195	0.0080	0.0037	0.2024	0.0392	0.0047	0.0048	0.0020	0.0030	0.0037	0.0574	
F	0.7	600	0.0230	0.0177	0.0170	0.0170	0.0030	0.0130	0.0907	.....	.....	.....	.....	.....	.....	.....	
G	5.2	35	0.0439	0.0415	0.0245	0.0226	0.0212	0.0115	0.1652	0.0094	0.0025	0.0000	0.0011	0.0087	0.0000	0.0217	
H	9.8	600	0.0140	0.0121	0.0041	0.0108	0.0089	0.0093	0.0592	0.0044	0.0040	0.0000	0.0000	0.0005	0.0028	0.0117	
I	8.5	480	0.0240	0.0229	0.0118	0.0120	0.0055	0.0080	0.0842	.....	.....	.....	.....	.....	.....	.....	
K	9.8	20	0.0694	0.0437	0.0386	0.0278	0.0187	0.0150	0.2132	0.0164	0.0092	0.0061	0.0053	0.0059	0.0043	0.0432	
K^1	9.8	210	0.0317	0.0299	0.0262	0.0229	0.0110	0.0055	0.1272	0.0117	0.0074	0.0037	0.0079	0.0035	0.0005	0.0347	Same cement, but 2 months older.
K^2	9.8	360	0.0897	0.0679	0.0406	0.0247	0.0248	0.0105	0.2582	.....	.....	.....	.....	.....	.....	.....	The same cement, with 1 per ct. of gypsum.
K^3	9.8	600	0.0966	0.0625	0.0335	0.0274	0.0154	0.0193	0.2547	0.0266	0.0150	0.0000	0.0034	0.0029	0.0108	0.0497	Do. with 2 per cent. of gypsum.
K^4	9.8	840	0.4131	1.0335	0.3122	0.0202	0.0100	0.0139	1.8029	0.1396	0.3035	0.0200	0.0024	0.0025	0.0039	0.4719	Do. with 5 per cent. of gypsum.
L	7.3	120	0.0428	0.0449	0.0313	0.0207	0.0080	0.0030	0.1507	0.0178	0.0124	0.0097	0.0048	0.0000	0.0010	0.0457	L cement.
L^1	7.3	420	0.0543	0.0499	0.0322	0.0198	0.0080	0.0030	0.1672	0.0168	0.0124	0.0027	0.0043	0.0030	0.0000	0.0392	Do. with 1 per cent. of gypsum.
L^2	7.3	600	0.1013	0.0424	0.0228	0.0267	0.0080	0.0030	0.2042	0.0259	0.0078	0.0062	0.0033	0.0030	0.0005	0.0467	Do. with 2 per cent. of gypsum.
M	9.3	30	0.0530	0.0272	0.0167	0.0098	0.0072	0.0058	0.1197	.....	.....	.....	.....	.....	.....	.....	M cement.
M^1	9.3	300	0.0599	0.0353	0.0167	0.0148	0.0047	0.0083	0.1397	.....	.....	.....	.....	.....	.....	.....	Do. with 1 per cent. of gypsum.

5. It is greater with new cement, and least with that which has been kept in stock.

6. It is increased by the admixture of gypsum.

7. Other experiments show that it is greatest with over-limed or highly-burned cements, and that all cements contract when drying, and expand on being put into water.

The expansion was progressive for a year, and amounted to 0.09 of 1 per cent. to 0.21 for the neat cements without gypsum; and to 0.01 to 0.06 of 1 per cent. for the mixture with three parts sand. With gypsum the figures went up to $1\frac{8}{10}$ per cent. and 0.47 per cent. respectively.

In comparing the results from this table with the previous one, it should be borne in mind that these experiments are on English Portland cements, and those of the former table on German and French cements.

Those of Table No. 3, the later ones, do not agree very closely with the earlier ones given in Table No. 4, as published at the time by the Messrs. Dykerhoff.

For example, the average coefficient of expansion for pure Portland cement determined from nine different kinds, 16 weeks old, is by Table No. 3, .000408, which represents the percentage of its length that the average specimen expanded immersed in water.

By Table No. 4, under the same conditions the average coefficient of expansion for pure Portland cement determined from nine different kinds of cement is .000991, or more than double that of Table No. 3.

By Table No. 4 the average coefficient of expansion for Portland cement-mortars, 1 part cement, 3 parts sand by weight, 16 weeks old, immersed in water, is .000221, while by Table No. 3 it is .000067 for the same kind of mortars.

Therefore for pure Portland cements the average coefficients from Table No. 3 are less than half of those which are taken from Table No. 4, while for cement-mortars the average coefficients from Table No. 4 are about three times those taken from Table No. 3.

This variation in the comparison of the average results derived from the two tables throws some doubt over the accuracy of the whole experiments, and makes it quite a fair question whether the errors incidental to the smallness of the measurements and the size of the specimens do not make tabulated expansion of little value in exact calculations for practice.

The great benefit really conferred upon engineering science by these

very careful experiments, made with apparatus especially designed to remove and compensate for most of the errors peculiar to all fine measuring instruments, appears to be in the general deductions that we can make with reasonable assurance of their being accurate, such as the facts that are the same in both tables and are in accord with "the experience of practice" to quote Mr. Faija's expression on this question.

The most salient of these facts are:

First.—That all pure Portland cements and Portland cement-mortars when left in the air, contract from the second day after gauging, onward through at least four months, and probably more.

Second.—All pure Portland cements and Portland cement-mortars when immersed in water, expand from the second day after gauging onward through at least one year.

Third.—All pure Portland cements, after gauging, expand and contract more than when mixed with sand.

Fourth.—All pure Portland cements and Portland cement-mortars contract much more when left in the air than they expand when immersed in water.

While these general facts are pretty clearly proven, the experiments (in a similar manner to those made on the expansion and contraction of cement-mortars when exposed to changes of temperature) show elements of doubtfulness when we endeavor to deduce from these coefficients to be used in designing work,

For example: A monolithic wall, 1 000 meters long, made of cement-mortar (1 part Portland cement, 3 parts sand), between abutments supposed to be immovable, and immersed in water, would, at the expiration of twelve months from the date of its construction, and independently of temperature changes, increase its length about 0.31 meters (12.2 inches), according to Table No. 4, or nearly the same as it would after undergoing a change of temperature of 54 degrees Fahrenheit according to coefficients from M. Bouniceau, "Annales des Ponts et Chaussées," 1863. (See Transactions Am. Soc. C. E., Vol. XIV., page 495.) Now most engineers familiar with walls of this character would be quite unwilling to accept the above expansions, derived though they are from careful experiments on small specimens, in the light of "the experience of practice."

The same wall, as stated above, if instead of being built in water had been allowed to harden in the air, would at the expiration of four months, according to Table No. 3, have contracted about 0.98 meters

(38.5 inches), independently of all changes in volume due to temperature changes. This deduction is still more at variance with our experience than the preceding.

Mr. Henry Faija, in his work on cement, entitled "Cement for Users," last edition, 1884, discusses Table No. 4, and vainly endeavors to reconcile it with the record of all large concrete works, such as the New Victoria Docks, where the vertical cracks indicate contraction, and yet by Table No. 4, expansion is shown in all cases.

This difficulty would have entirely disappeared if Mr. Faija had seen Bauschinger's later experiments as embodied in Table No. 3, where contraction is shown in every case for mortars in *air;* just as *expansion* is shown in every case for mortars in water by Table No. 4.

In this connection the experience of the Department of Docks of New York gives important information. Over ten years ago, when the upper portion of the new bulkhead walls, built of Portland cement concrete, began to extend over considerable distances in monolithic masses, vertical cracks began to appear at irregular intervals. To remedy this difficulty, vertical joints were placed in the masonry as it was built, at intervals from 150 to 200 feet apart. These joints have opened about ¾ of an inch, and do not seem to be affected by temperature changes. They have also stopped the irregular vertical cracks from appearing.* As about half of the concrete in this part of the wall is alternately wet and dry by the action of the tide, about one-fourth is immersed all the time, and about one-fourth is out of water all the time; the resultant contraction, that undoubtedly takes place, is the component of the forces of contraction and expansion which occur sometimes together and sometimes separately as the wall is submerged by the tide.†

Although so much prominence has been given of late years to the economy of employing beton and concrete in large quantities in monolithic structures, very little notice has been taken by engineers of the serious effects of contraction on all concrete work that hardens in the air. The makers of artificial stone pavements, after innumerable fail-

* If a mean be taken of the changes in 12 months time in air or water, we have 38.5 —12.2 = 13.1 inches contraction. A wall 1 000 meters, or 3 936 feet, is equal to say twenty lengths of 200 feet. And if one such length contracts ¾ inch as mentioned, twenty would contract 15 inches.

† After the earth filling is deposited in rear of the wall to grade, it is doubtful if any of the concrete is ever dry below high-water mark, on account of the absorption and retention of the tide-water.

ures, soon found that the contraction of the cement in setting could only be successfully resisted by the introduction of joints properly arranged, and where these joints are not used in large concrete construction, trouble is sure to be experienced. In the building of fourteen large kilns for burning cement, about three years ago, concrete made of Rosendale cement was employed. In the plan the kilns were built in one piece of concrete masonry, about 50 by 20 by 150 feet, with the necessary openings and arches. Shortly after construction and use serious cracks appeared, and rendered necessary extensive repairs which were never satisfactory. If vertical joints had been properly placed, no trouble would have arisen. The Vanne Aqueduct in France is another case in point of engineers employing beton and concrete without provision for contraction. This aqueduct, mentioned by General Gillmore in his work entitled "Béton Agglomèré," as an example of the successful application of beton and concrete in monolithic construction, was built about twenty years ago, and is now, according to the testimony of French engineers, in bad condition. Cracks have appeared in so many places, and are still appearing, that the leakage question has become a very serious one. In addition to this several of the large *beton coignet* arches have been propped up by building cut-stone masonry arches underneath them to prevent their fall.

In this case, in the light of our advance in knowledge of the material of which the aqueduct is built, it seems reasonably fair to suppose that if vertical joints had been introduced over the piers at suitable distances, few of the cracks now so troublesome would have appeared.

With regard to failure of the arches, while contraction unprovided for might be an important factor in the case, the French engineers ascribe it to the use of *beton coignet.*

A series of experiments now in progress show that both Portland and Rosendale cements, when mixed neat, absorb about the same amount of water as when mixed with two parts sand, and the absorption is probably least for that proportion of cement which just fills the spaces in the sand. Since the expansion of cement-mortars hardening under water is greatest when neat cement is used, it is possible that there is some connection between absorption and expansion. This might also explain the greater contraction of neat cement-mortars.

These results are sufficient to show that the quantities involved, while of no importance to structures of moderate expansions, may become of

very great moment when great heights or great lengths of masonry are involved.

The unexplored region is that pertaining to the important changes occurring during the first 48 hours after mixing; the question as to whether the changes are the same during induration, whether occurring under pressure or not; and the investigation of nearly the whole range of changes which occur in our native cements.

All experiments in this direction should be on sufficiently large specimens to eliminate small errors in observation, and all circumstances of temperature and moisture should be completely observed.

The Committee therefore ask to be continued.

F. Collingwood,
D. J. Whittemore,
W. W. Maclay,
T. C. McCollom,
Thomas L. Casey,
George F. Swain,
Arthur V. Abbott,
Committee.

AMERICAN SOCIETY OF CIVIL ENGINEERS.
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TRANSACTIONS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

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(Vol. XV.—November, 1886.)

ENGLISH AND AMERICAN RAILROADS COMPARED.

By EDWARD BATES DORSEY, M. Am. Soc. C. E.

SUPPLEMENTARY PAPER, READ MAY 5TH, 1886.*

WITH DISCUSSION.

Since the first part of my paper was prepared, I have passed nearly a year in England, observing closely the railroad question, especially the data from which I obtained the passenger and ton mileage—which is really the basis of the whole comparison. I again repeat my concluding remarks from page 75 of my paper: "He (the author) hopes that the railroads which are so largely interested in this question, will promptly replace his estimates by their official figures. Until this is done, he claims that these figures should be accepted as correct."

The following Table, No. 42, which I had not time to finish before my paper was read, shows the expense of transporting one ton or one passenger one mile on some of the leading railroads of England and the United States, and also the comparative expense per train mile. To make the comparison more general, all the railroads of England and Wales, embracing 13 340 miles, are compared with all the roads of Massachusetts, embracing sixty-three companies, operating 2 852 miles,

* English and American Railroads Compared. By Edward Bates Dorsey, M. Am. Soc. C. E. Transactions, No. 318, Vol. XV, p. 1, January, 1886.

TABLE No. 42.

Showing the Cost per Train Mile and Ton, or Passenger Mile in Operating different Railroads in England and the United States.

NAME OF RAILROAD.	Total Length of Line Operated.	Total Mileage.		Total Passenger and Ton Mileage.	Average Load of Train.		Average Length of Haul.		Average Cost of Operating Expenses.	
		Passenger.	Ton.		Passenger.	Ton.	Passenger.	Ton.	Per Train Mile.	Transporting one Passenger, or one Ton, one Mile.
UNITED KINGDOM, 1883.	Miles.						Miles.	Miles.	Dollars.	Cents.
Great Northern	768	286 512 050	502 973 520	789 485 570	35	61	10	53	0.587	1.22
North Eastern	1 534	359 184 052	1 159 691 280	1 518 875 332	37	78	9	29	0.677	1.10
Midland	1 381	432 151 874	1 222 309 920	1 654 461 794	33	61	12	48	0.563	1.12
London and North Western	1 793	745 749 134	1 511 779 440	2 257 528 574	39	78	12	42	0.655	1.11
Great Western	2 268	642 025 920	1 042 489 200	1 684 515 120	45	65	12	43	0.600	1.09
Great Eastern	1 049	386 454 286	369 094 320	755 548 606	45	69	5	52	0.630	1.15
London and South Western	721	406 375 606	216 649 920	623 025 526	51	71	9	59	0.716	1.28
London, Chatham and Dover	160	195 917 102	60 534 960	256 452 062	62	89	5	28	0.828	1.14
Caledonian	877	195 721 238	456 161 700	651 882 938	37	69	10	30	0.636	1.16
North British	1 006	193 726 340	396 243 120	589 969 460	38	61	8	29	0.570	1.12
London, Brighton and South Coast	403	369 993 492	130 318 080	500 311 572	57	91	6	51	0.661	1.05
1884.—All the Railroads of England and Wales (average cost per mile, £49 258)	13 340	5 199 240 104	.....	12 872 762 744	43	72	8	35	0.640	1.14
UNITED STATES, 1884.										
Boston and Lowell	550	61 343 056	59 427 991	120 771 047	43	97	14	40	1.083	1.72
Boston and Maine	204	89 587 566	44 937 544	134 525 110	69	83	13	47	1.137	1.55
Boston and Providence	68	55 200 708	21 814 483	77 015 191	76	89	10	30	1.399	1.77
Old Colony	468	116 745 901	57 899 872	174 645 773	71	72	15	36	1.212	1.68
New York, New Haven and Hartford	265	206 677 775	125 743 803	332 421 578	87	86	26	58	1.261	1.45
New York, Lake Erie and Western	1 029	169 599 245	1 794 946 519	1 964 545 764	45	239	19	162	0.745	0.62
N. Y. Cent. and Hudson River Railroad	993	387 329 886	1 970 087 115	2 357 919 001	60	196	60	193	1.085	0.74
Penn. Railroad, Penn. Railroad Div.	1 471	244 710 876	2 996 892 567	3 241 633 443	42	205	21	134	0.845	0.53
All the Railroads of Massachusetts (average cost per mile, $69 281)	2 852	1 007 136 376	1 229 368 472	2 236 504 848	67	110	15	60	1.173	1.38

averaging less than fifty miles per road to each company. It is evident that these small companies are operated at much greater expense, in proportion to their business, than the larger ones, as they cannot afford to hire such efficient management, or buy their supplies on such favorable terms as the larger companies, who make their purchases in very large quantities.

Explanation of Tables.

In all cases the aggregate daily train mileage was obtained by assuming that the reported annual revenue train mileage was made in 315 working days; thus divide total annual revenue freight and passenger train miles by 315; then divide this quotient by the length of line operated.

In all cases the revenue mileage only has been counted, the working trains and switching mileage being excluded.

Except in the case of the New York Central and Hudson River Railroad, all canal, dock and steamboat expenditures have been excluded.

Mr. T. Russell Crampton, M. Inst. C. E., the celebrated English engine-builder, in a recent paper before the French Society of Engineers (see *London Engineer* of this year, page 354), estimated the average cost on six of the largest English railroads of repairs and renewals of locomotives at over 3d. per train mile; this is somewhat higher than my figures from the official reports of the companies.

No reports or returns have been received for 1885 from the English railroads or the Board of Trade.

The cost has been taken from the reports of the respective companies, or from the Reports of the Board of Trade of the United Kingdom.

Except when otherwise stated, taxes and duties have been included in the operating expenses.

I will repeat again, that no returns are made in England of the ton or passenger mileage, nor is there any attempt made to separate the cost of the freight or passenger traffic; consequently it has been necessary for comparison to add them together.

My plan for estimating the ton and passenger mileage was fully described on page 16, volume XV of the Transactions of this Society.

TABLE No. 43.

Showing the Average Cost of Transporting One Ton or One Passenger One Mile on the Boston and Albany Railroad for the Last 18 Years.

Year.	Cents.	Year.	Cents.
1868	.0202	1877	.0088
1869	.0188	1878	.0083
1870	.0174	1879	.0071
1871	.0178	1880	.0087
1872	.0171	1881	.0083
1873	.0172	1882	.0083
1874	.0122	1883	.0090
1875	.0111	1884	.0081
1876	.0096	1885	.0072

By inspecting Table No. 42, it appears that the cost of transporting one ton one mile in England and Wales is about the same as transporting one passenger the same distance; this is shown in the last column under the head, "Cost of transporting one passenger, or one ton, one mile." This cost is very uniform on all the English railroads, notwithstanding the great variation in the proportion of total ton and passenger mileage, running from one passenger to three tons on the Midland and North Eastern Railways, costing 1.12 and 1.10 cents respetively, to three passengers to one ton on the London, Brighton and South Coast, and London, Chatham and Dover Railways, which cost 1.05 and 1.14 cents respectively.

This result is the natural consequence of the small average load on the freight trains, which resemble too closely for economy the passenger trains in speed, load and cost.

The average cost in 1884 of the train mile on all the railroads of England and Wales was $0.64. On all the railroads of Massachusetts it was $1.17, or nearly double, while the average train load is more than fifty per cent. larger in passengers and tons on the Massachusetts railroads.

The average cost in 1884 of transporting one passenger, or one ton, one mile on the English and Welsh railroads, was $0.0114; on the railroads of Massachusetts it was $0.0138, or 21 per cent. more. This is the actual

cost: no allowance has been made for the difference in cost of labor, materials and fuel. The pay of the engine-drivers and firemen in Massachusetts is more than double what it is in England and Wales. The price of fuel is fully three times as much. All wages will probably average 50 per cent. more, and all materials, except ties (sleepers) and lumber, are higher.

It is evident that if proper reductions are made for the difference in the cost of fuel, labor and materials in the two countries, the American railroads are operated much more economically than those of the United Kingdom, otherwise it will have to be admitted that American labor, at nearly double the price, is as cheap as English at about half the price. Either the American railroad management is more economical, or the American labor is more efficient.

If the American rolling stock is not better than the English, why have the Midland and other English railroads adopted so extensively the bogie-truck? And why has it been adopted so thoroughly in Canada, where all the railroads were built by English capital, and mostly by English engineers? Many roads were equipped at first with English-built rolling stock, which was afterwards changed to the American type?

It is instructive to compare the progress made in railroad traffic and its economics within the past thirty years. The able work of Messrs. Alexander L. Holley and Zerah Colburn* gives very reliable data for the years 1855 and 1856. In the following comparisons all the figures given for these years have been taken from their work, except those relating to the Pennsylvania Railroad. The figures for 1884 for English railroads have been taken from the Railway Returns of the Board of Trade, and for the American railroads from the Reports of the Railroad Commissioners of New York and Massachusetts.

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*Strange as it may seem, it is only within the last few days that I have seen, for the first time, this book. At the time it was published and for many years afterward, I was engineering near the top of the Andes in South America, far removed from book-stores and libraries. Messrs. Holley and Colburn used the same plan that I did for estimating the ton mileage of the English railroads.

TABLE No. 44.

Comparison of Railroad Traffic in England and the United States in the Years 1855 or 1856 and 1884.

	1855 or 1856.	1884.
Cost per train mile:		
All railroads in England	*a* $0.68	*la* $0.61
London and North Western	*a* 0.79	*a* 0.63
All railroads in New York	*a* 1.00	*b* 1.01
All railroads in Massachusetts	*a* 1.05	*b* 1.17
Pennsylvania Railroad	*h* 1.39	*h* 0.84
Cost of transporting one ton or one passenger one mile:		
All railroads of England	*a* 0.0115	*a* 0.0115
All railroads in New York	*a* 0.0160	*a* 0.0078
Pennsylvania Railroad	*h* 0.0231	*h* 0.0054
Average train load—passengers:		
All railroads of England	46	43
All railroads of New York	73	51
Pennsylvania Railroad	*h* 57	*h* 42
Average train load—tons:		
All railroads of England	55	72
All railroads of New York	71	183
Pennsylvania Railroad	*h* 61	*h* 205
Average charge per ton per mile:		
All railroads of England	*c* $0.0275	*c* $0.0200
All railroads of New York	*f* 0.0250	0.0083
Pennsylvania Railroad	*h k* 0.0375	*h* 0.0074
Average charge per passenger per mile:		
All railroads of England	0.0252	*d* 0.0209
All railroads of New York	0.0198	*f* 0.0208
Pennsylvania Railroad	*h* 0.0325	*h* 0.0242

a—Exclusive of taxes and duties.

b—Inclusive of taxes and duties.

c—Messrs. Holley and Colburn estimate the average charge for all kinds of freight in 1855 was $0.0275 per ton of 2 000 pounds. My estimate in 1884 is $0.0200 per ton of 2 240 pounds. This, probably, is one-fourth too low.

d—Including first, second and third-class ordinary and season tickets. Without the season tickets the average is estimated at $0.0233.

f—For 1856, from the report of the State Engineer.

h—For 1856 and 1884, from reports of the Pennsylvania Railroad Company.

k—Exclusive of State tolls.

l—Including taxes and duties, $0.64.

From the preceding table it appears that from 1855 to 1884, thirty years, the railroads of England have reduced their expenses per train mile 10 per cent., and have decreased their train load in passengers 7 per cent., and increased their train load in freight 31 per cent.

The cost of transporting one passenger, or one ton, one mile has remained practically the same, being in 1855, 1.15 cents, and in 1884, 1.13 cents.

The average freight charge in 1855, per ton of 2 000 pounds, was 2.75 cents; in 1884, was 2 cents per ton of 2 240 pounds. (This is the price I estimate; probably 2.5 cents would be more correct.) The average charge or fare per passenger per mile in 1855 was 2.52 cents; in 1884 it was 2.09 cents. This last includes all three classes, and ordinary and season tickets; without including season tickets, the average fare for all classes I estimate at 2.33 cents per mile.

In 1855 the average cost per train mile on all the railroads of New York was $1; in 1884 it was $1.01, an increase of one per cent. The train load in 1855 averaged 73 passengers; in 1884 the average was 51, a decrease of 30 per cent; while the freight train load had increased from an average of 71 tons in 1855 to 183 tons in 1884, a gain of 159 per cent. The average cost of moving one ton, or one passenger, one mile in 1855 was 1.60 cents; in 1884 it was .78 cents, a decrease of 51 per cent.

The Pennsylvania Railroad in 1856 charged per mile per passenger $0.0325; in 1884, $0.0242, showing a reduction of one-fourth. In 1856 the freight charge per ton per mile (exclusive of State tolls) was $0.0375; in 1884 it was $0.0074, a reduction of 80 per cent. In the same time the cost of transporting one passenger, or one ton, one mile decreased from $0.0231 to $0.0053, or 76 per cent.

On the American railroads much greater saving has been made in the freight than in the passenger traffic.

The English railroads, in economical workings and appliances, have apparently remained stationary during the last thirty years, while the American roads have improved so as to reduce the operating expenses more than one-half. On freight alone some roads have reduced their expenses and charges 80 per cent.

SUPPLEMENTARY PAPER READ July 5, 1886.

In my previous paper the comparisons were confined to the railroads in the Middle or Eastern States. In this paper, with three exceptions, I will include in the comparisons the railroads in the Western and Southern States. These roads may be said to represent the true type of American railroad practice—they were cheaply constructed, and have been or are gradually being perfected, mostly from the earnings, while being operated. They are in the transition stage. Many bridges, buildings, etc., of wood, have been or are being replaced with iron or other durable material; iron rails with steel rails, etc. Until these changes are completed, the maintenance of way and operating expenses must necessarily appear large.

The Louisville and Nashville system embraces 2 065 miles of road. Average total cost per mile $43 004, being about the average capital increase per mile of the English roads in the last fifteen years, thus:

	1870.	1884.
Average paid up capital per mile of all the railroads of the United Kingdom.....	£34 106	£42 486
Increase in fifteen years.....		8 380

The reported increase of rolling stock will only account for about £1 000 of this increased capital.

A careful inspection of Table No. 45 will show the following results for work actually done, *i. e.*, the cost of transporting 1 ton or 1 passenger 1 mile on our well-constructed roads, such as the New York Central and Hudson River, Pennsylvania, Chicago, Rock Island and Pacific, Louisville and Nashville, main stem, etc., the cost compared with the English roads is about one-half for maintenance of way, repairs and renewals of locomotives and motive power, and from half to three-quarters for total operating expenses.

On the roads of low cost and inferior construction, with few exceptions, the average cost of these items for 1885 was less than on the English roads—varying from one-half to seven-eighths.

For comparison, let us select from Table No. 45 the London and North Western Railway, and the Pennsylvania Railroad Division of the Pennsylvania Railroad. Each of these may truly be said to be the most perfect and extensive of their respective types.

TABLE No. 45.

Comparing the Cost of Maintenance of Way, Repairs and Renewals of Locomotives, Motive Power, and Total Operating Expenses.

Name of Railroad.	Year.	Average Length of Line Operated.	Aggregate Daily Trains Over Entire Line.	Average Cost per Mile.	Average Load of Train.			Total Cost of Maintenance of Way.		Total Cost of Repairs and Renewals of Locomotives.		Total Cost of Motive Power.		Total Cost of Operating Expenses.	
					Tons.	Passengers.	Tons and Passengers.	Per Train Mile.	Per 1 Ton or 1 Passenger Moved 1 Mile.	Per Train Mile.	Per 1 Ton or 1 Passenger Moved 1 Mile.	Per Train Mile.	Per 1 Ton or 1 Passenger Moved 1 Mile.	Per Train Mile.	Per 1 Ton or 1 Passenger Moved 1 Mile.
UNITED KINGDOM. £ = $4.80. d = 2 cents.		Miles.						Cents.	Cents.	Cents.	Cents.	Cents.	Cents.	Cents.	Cents.
Caledonian	1882	.....	.....	.....	....	.....	.....	10.46	.....	.....	.....	15.26	.....	62.40	.....
	1883	877	43	.....	69	37	55	9.54	.174	5.06	.092	15.92	.290	63.64	1.16
	1884	878	45	.....	61	35	51	10.08	.198	5.22	.102	16.26	.302	60.26	1.18
Great Eastern	1882	.....	.....	.....	....	.....	.....	10.48	.....	.....	.....	17.32	.....	64.42	.....
	1883	1 049	42	.....	69	45	55	10.30	.188	5.30	.095	17.88	.325	63.04	1.15
	1884	1 038	43	.....	68	46	55	9.96	.180	5.06	.092	17.12	.311	61.24	1.11
Great Northern	1882	.....	.....	.....	....	.....	.....	9.54	.....	.....	.....	15.20	.....	59.58	.....
	1883	768	68	.....	61	35	48	9.50	.198	4.00	.083	15.50	.322	58.72	1.22
	1884	785	69	.....	60	34	47	9.20	.196	4.02	.086	15.24	.324	56.24	1.20
Great Western	1882	.....	.....	.....	....	.....	.....	14.30	.....	.....	.....	15.14	.....	59.92	.....
	1883	2 268	42	.....	65	45	55	14.22	.259	5.80	.105	15.26	.277	60.04	1.09
	1884	2 301	42	.....	64	44	54	13.80	.255	.....	.....	15 38	.285	59.34	1.10
Great Southern and Western of Ireland	1882	.....	.....	.....	....	.....	.....	15.48	.....	.....	.....	18.55	.....	69.40	.....
	1883	478	19	.....	74	40	54	17.28	.320	6.00	.111	18.62	.345	68.94	1.28
	1884	496	19	.....	73	37	52	16.26	.313	5.96	.115	18.18	.350	67.30	1.30
Lancashire and Yorkshire	1882	.....	.....	.....	....	.....	.....	12.56	.....	.....	.....	19.26	.....	77.32	.....
	1883	494	84	.....	99	42	66	12.78	.194	.....	.....	17.52	.267	75.12	1.14
	1884	496	88	.....	96	41	64	12.46	.195	.....	.....	16.20	.253	71.05	1.11
London and North Western	1882	.....	.....	.....	....	.....	.....	12.40	.....	.....	.....	15.10	.....	66.54	.....
	1883	1 793	68	.....	78	39	59	11.90	.202	4.60	.078	15.40	.261	65.52	1.11
	1884	1 811	68	.....	78	38	58	12.14	.209	4.78	.082	15.72	.271	65.65	1.13
London and South Western	1882	.....	.....	.....	....	.....	.....	13.60	.....	.....	.....	15.90	.....	73.28	.....
	1883	721	49	.....	71	61	56	12.78	.228	5.42	.097	16.56	.298	71.58	1.28
	1884	722	49	.....	69	51	56	13.06	.233	5.42	.097	19.38	.346	71.46	1.27
London, Brighton and South Coast	1882	.....	.....	.....	....	.....	.....	9.82	.....	.....	.....	18.06	.....	66.52	.....
	1883	403	63	.....	91	58	63	9.96	.158	4.24	.067	18.20	.289	66.08	1.05
	1884	417	62	.....	83	55	61	9.80	.161	4.48	.073	17.94	.294	63.70	1.05
Manchester, Sheffield and Lincolnshire	1882	.....	.....	.....	....	.....	.....	9.26	.....	.....	.....	14.36	.....	66.18	.....
	1883	314	66	.....	77	35	62	8.92	.160	.....	.....	14.90	.248	65.48	1.05
	1884	316	69	.....	75	34	60	8.80	.147	.....	.....	14.26	.238	65.02	1.08
Midland	1882	.....	.....	.....	....	.....	.....	10.18	.....	.....	.....	14.94	.....	56.18	.....
	1883	1 381	76	.....	61	33	50	9.50	.190	5.24	.105	15.50	.310	56.30	1.12
	1884	1 388	76	.....	61	33	50	8.96	.180	5.06	.101	15.34	.301	56.52	1.13
North Eastern	1882	.....	.....	.....	....	.....	.....	12.78	.....	.....	.....	20.50	.....	69.14	.....
	1883	1 534	51	.....	78	37	62	12.36	.199	7.84	.126	21.24	.343	67.74	1.10
	1884	1 534	49	.....	76	35	59	12.38	.210	8.34	.141	21.50	.364	67.78	1.15
South Eastern	1882	.....	.....	.....	....	.....	.....	11.08	.....	.....	.....	17.54	.....	74 44	.....
	1883	370	55	.....	85	66	71	10.78	.152	3.88	.055	18.02	.255	74.74	1.05
	1884	369	59	.....	82	62	66	9.94	.151	3.92	.060	17.22	.261	70.58	1.07
All the Railroads of the United Kingdom	1882	18 457	.....	£41 605	....	.....	.....	12.28	.....	.....	.....	16.42	.....	54.94	.....
	1883	18 681	46	42 417	73	43	57	12.02	.211	.....	.....	16.64	.291	64 34	1.13
	1884	18 864	46	42 486	71	42	55	11.54	.211	.....	.....	16.70	.304	63.18	1.15
All the Railroads of England and Wales	1882	.....	.....	.....	....	.....	.....	12.12	.....	.....	.....	16.74	.....	65.68	.....
	1883	13 215	54	49 258	73	44	57	11.74	.206	.....	.....	16.96	.300	64.84	1.14
	1884	13 340	54	49 854	72	43	56	11.44	.204	.....	.....	17.04	.304	63.96	1.14
UNITED STATES.															
Pennsylvania Railroad Division	1883	1 314	52	.....	189	45	152	17.6	.116	7.1	.047	24.5	.161	86.	.56
	1884	1 471	45	.....	205	42	160	16.4	.103	7.	.044	23.8	.148	84.5	.63
	1885	1 518	46	.....	210	45	167	13.2	.080	6.2	.037	22.2	.133	78.2	.41
New York Central and Hudson River	1883	.....	.....	.....	205	71	160	21.7	.134	6.8	.042	34.3	.214	123.2	.77
	1884	993	53	.....	196	60	147	18.8	.128	5.2	.035	26.6	.180	108.5	.74
	1885	993	56	.....	195	70	150	15.1	.100	4.9	.033	24.8	.165	92.8	.63
Louisville and Nashville System, Main Stem	1883	185	21	$85 405	149	40	109	13.15	.121	4.51	.041	20.60	.190	86.31	.783
	1884	185	23	86 373	145	59	112	10.46	.093	4.54	.041	20.57	.184	85.39	.762
	1885	185	21	86 804	149	58	114	10.96	.096	4.13	.036	18.67	.154	81.08	.716
Nashville and Decatur	1883	119	15	37 198	153	39	116	17.18	.151	4.57	.039	20.47	.176	103.94	.896
	1884	119	15	37 420	161	49	125	13.59	.109	4.58	.037	21.06	.168	97.21	.777
	1885	119	15	37 769	162	64	128	12.57	.098	4.16	.033	20.25	.159	91.39	.714
South and North Alabama	1883	189	17	55 367	129	34	103	21.18	.205	4.66	.045	19.67	.191	89.45	.869
	1884	189	18	55 521	124	45	107	15.32	.143	4.74	.044	19.48	.182	87.00	.813
	1885	189	19	55 818	117	57	101	10.99	.109	4 25	.042	18.57	.184	75.57	.748
Mobile and Montgomery	1883	179	12	36 059	137	43	105	23.12	.220	4.56	.043	19.07	.181	95.38	.908
	1884	179	13	36 119	129	52	104	28.38	.273	4.67	.045	19.42	.187	104.35	1.000
	1885	179	14	36 154	123	75	104	22.91	.220	4.09	.039	18.18	.175	92.42	.889
New Orleans, Mobile and Texas	1883	141	12	73 052	150	64	110	18.74	.170	4.34	.039	20.86	.190	99.08	.901
	1884	141	12	73 195	143	80	112	22.08	.197	4.54	.040	21.61	.193	107.	.955
	1885	141	12	73 241	138	93	114	15.05	.141	3.91	.034	20.78	.174	94.07	.843
Knoxville Branch	1883	171	4	28 200	134	42	91	50.78	.558	4.33	.048	21.25	.233	111.81	1.229
	1884	171	10	26 464	122	39	88	35.53	.404	4.50	.052	21.04	.239	93.94	1.069
	1885	171	11	26 624	126	31	91	22.16	.243	4.14	.045	19.11	.210	74.55	.819
Memphis Line	1883	258	10	35 667	100	32	69	24.26	.352	4.36	.063	18.65	.270	83.74	1.212
	1884	258	9	35 702	110	39	76	22.82	.300	4.53	.059	19.65	.259	84.58	1.113
	1885	258	9	35 710	125	34	81	21.84	.270	4.00	.049	19.44	.240	84.35	1.041
Henderson Division	1883	151	14	41 782	126	27	93	22.17	.238	4.57	.047	19.68	.212	82.76	.890
	1884	151	13	41 854	138	42	116	25.00	.216	4.76	.041	19.77	.170	93.77	.808
	1885	151	13	41 904	152	45	125	15.98	.128	4.25	.034	17.29	.138	80.60	.645
St. Louis Division	1883	208	8	33 108	109	32	74	34.08	.460	4.35	.060	16.45	.222	102.97	1.391
	1884	208	9	33 297	109	33	75	32.17	.429	4.56	.061	17.04	.217	101.41	1.852
	1885	208	9	33 372	122	32	82	28.32	.345	4.05	.049	15.86	.193	93.35	1.139
Cincinnati Division	1883	110	17	44 469	113	41	80	16.87	.201	4.34	.054	21.04	.263	107.81	1.348
	1884	110	18	44 689	125	51	92	15.75	.171	4.56	.049	20.26	.220	105.86	1.161
	1885	110	19	44 391	135	45	95	14.55	.153	4.05	.042	18.98	.200	103.11	1.086
Lexington Branch	1883	67	10	44 469	103	37	60	38.14	.636	4.03	.067	18.63	.310	96.84	1.614
	1884	67	11	44 533	159	48	90	27.71	.308	4.39	.048	19.16	.213	88.63	.985
	1885	67	11	44 564	165	40	91	20.95	.230	3.90	.043	17.84	.200	78.73	.865
Chicago, Rock Island and Pacific	1883	1 384	22	52 203	109	53	95	17.12	.180	3.81	.035	16.83	.177	77.50	.817
	1884	1 384	25	52 963	110	49	94	14.08	.150	3.53	.037	16.85	.177	72.43	.767
	1885	1 384	22	53 221	106	52	93	14.67	.158	3.18	.034	18.08	.194	74.32	.804
Philadelphia and Erie	1883	287	26	.....	268	44	221	25.61	.115	9.32	.042	31.17	.141	107.14	.473
	1884	287	26	.....	279	38	221	21.15	.096	9.57	.043	28.03	.127	93.58	.423
	1885	287	26	.....	288	35	229	18.06	.079	7.77	.034	25.48	.111	83.10	.360

TABLE No. 46.

London and North Western Railway, of England, compared with the Pennsylvania Railroad Division of the Pennsylvania Railroad, of the United States:

1884.	London and North Western.	Pennsylvania Railroad Division.
Total length of line operated	1 811	1 471
Aggregate daily trains over entire line	68	45
Average annual train mileage per mile of line operated	21 086	14 135
Average load of freight trains, tons	78	205
Average passenger trains, passengers	38	42
Average of all trains, tons and passengers	58	160
Average Cost of Transporting One ton, or One passenger, One mile.	**Cents.**	**Cents.**
Maintenance of way	.209	.103
Repairs and renewals of locomotives	.082	.044
Total cost of motive power	.271	.148
Total operating expenses	1.130	.530

From the preceding table it appears that the actual cost of transporting one ton, or one passenger, one mile on the London and North Western is about double what it is on the Pennsylvania, in maintenance of way, repairs and renewals of locomotives, motive power and total operating expenses. To this last item, for the London and North Western there should be allowed a large credit, as, owing to the average length of haul for freight being shorter on that road than on the Pennsylvania, the terminal charges are proportionately greater.

It may be said that this calculation is based entirely upon my plan for estimating the ton and passenger mileage, *i. e*, the average charge of 1d. per ton per mile, and $1\frac{1}{6}$d. per passenger per mile for ordinary tickets, and .4d. per mile for season tickets, including first, second and third-class.

For argument sake we can reduce all these prices one-half, and by making proper allowance for the difference in the price of labor and materials that constitute almost entirely the different items of operating expenses, the Pennsylvania Railroad will still be found to cost less.

Suppose we substitute in the preceding table for the Pennsylvania Railroad, the Knoxville branch of the Louisville and Nashville system. This can be considered a fair sample of the cheaply constructed American railroad. It runs through, physically, a very rough, sparsely settled country, offering no natural advantage for cheap railroading. The traffic is so small that it only justifies a total of ten trains daily. The entire average cost of constructing this road is $26 464 per mile—less than one-ninth of the average cost of the London and North Western per mile.

TABLE No. 47.

London and North Western Railway, of England, compared to the Knoxville Branch of the Louisville and Nashville System.

1884.	London and North Western.	Knoxville Branch.
Total length of line operated	1,811	171
Total annual freight and passenger train mileage per mile of line operated	21 086	3 515
Average load of freight trains, tons	78	122
Average load of passenger trains, passengers	38	39
Average load of all trains, tons and passengers	58	88
Average Cost of Transporting One Ton, or One Passenger, One Mile.	**Cents.**	**Cents.**
Maintenance of way	.209	.404
Repairs and renewals of locomotives	.082	.052
Total cost of motive power	.271	.239
Total operating expenses	1.130	1.069

Notwithstanding the small traffic and the cheapness of construction of the Knoxville Branch, the cost for moving one ton, or one passenger one mile, for maintenance of way, is only .2 cent more, while all the other charges are less than on the London and North Western Railway, the total operating expenses being as 1.130 to 1.069 cents or .061 cent less.

The returns or reports of the London and North Western for 1885 have not been received by me. In 1885 the Knoxville Branch made

large savings in the cost of maintenance of way, and consequently in operating expenses, comparing thus:

TABLE No. 48.

Cost of Moving one Ton, or one Passenger, one mile.	London and North Western, 1884.	Knoxville Branch, 1885.
Maintenance of way.....	.209 cents.	.243 cents.
Total operating expenses	1.130 "	.819 "

This table shows the cost of maintenance of way to be nearly the same, while the total cost of operating expenses is 27 per cent. less on the cheap than on the expensively constructed road.

Some persons state that the reason of the greater cost of the different items forming the cost of operating expenses, is owing to the greater number of trains running on a given mile of the English railroads. This is unquestionably the cause of most of the increase, but is it a good reason for it ?

Can it be considered good practice to employ two men to do the same work that others are doing with less than one man? Is not this just what is being done now on the English railways, owing to the light freight and passenger trains that are run, requiring over two engines and two sets of men to do the same amount of work that the Americans do with one ?

It is difficult to say what causes this great difference in the cost of maintenance of way. Undoubtedly the rigid and stiff rolling stock used on the English roads runs with more friction and wear and tear than the pliable bogie-truck used on the American railroads.

TABLE No. 49.

Comparative Cost of Transporting one Ton, or one Passenger, one mile, in Maintenance of Way and Motive Power.

No Reports for 1885 from the London and North Western have been received.	London and North Western. Average of Years 1883 and 1884.	Pennsylvania Railroad Division. Average of Years 1883, 1884 & 1885.
Maintenance of way.....	.206 cent.	.100 cent.
Motive power	.266 "	.147 "
Total.....	.472 cent.	.247 cent.
	.247 "	
Excess of cost.....	.225 cent.	

This excess is more than half of the total cost of all operating expenses of the Pennsylvania Railroad in 1885.

It cannot be said that the Pennsylvania Railroad has favored to any serious extent these two accounts at the expense of others, as the total cost of all operating expenses in 1885 was less than the aggregate of these two items on the London and North Western.

If this amount could be saved, it would, on the traffic of the London and North Western Railway, amount to an annual saving of about ($5 000 000) five millions of dollars. This estimate is based upon the prices actually paid. This saving would be still more largely increased if proper allowances were made for the difference in the price of labor and material used on the two railroads.

I conclude this paper with the last sentence in my first paper on this subject.

"For what *is* done in the United States, *ought* to be done in the United Kingdom."

DISCUSSION ON

ENGLISH AND AMERICAN RAILROADS COMPARED.

Edward P. North, M. Am. Soc. C. E., suggested that the use of the term "bogie-truck" was hardly a proper expression, as the word truck is used in America to describe an American invention, and the word "bogie" is used in England applied to the same thing; one noun is used in this paper as an adjective to explain a noun of the same meaning.

Mr. Dorsey agreed with Mr. North that the simple word "truck" was more proper, but as the paper compared the railways of both continents, the terms used should be readily understood. All railroad men of Europe with whom he had conversed understood what is meant when the compound word "bogie-truck" is used, while, if the simple word "truck" is used, the meaning might have to be explained to many.

M. J. Becker, M. Am. Soc. C. E., thought it difficult to enter upon a comparison of English railroads as a whole with American railroads as a whole, because there exists in England a certain uniformity and general standard of operation, but in this country there is practically no standard at all. Some of our roads attain a high degree of excellence, approaching, if not excelling, the best in any other country, and other roads are scarcely worthy of the name. This seems to apply not only to the construction, but to the management as well.

He also thought that in the comparison of railroad speeds the necessity for stops and grade-crossings—which stops are often compelled by State laws—should be considered in comparing such roads with those where such stops are not necessary.

E. L. Corthell, M. Am. Soc. C. E., agreed with Mr. Becker and said that it was hardly fair to compare the speed upon one railroad with another until the curves, grades, stops, etc., should be considered.

Walter Katte, M. Am. Soc. C. E., referred to speed attained on the New York, West Shore and Buffalo Railway, as stated in Mr. Dorsey's paper at page 65 of the Transactions for 1886.

Mr. Dorsey replied that he had taken the ground that the object of fast traveling is to get the traveler to his destination as quickly as possible, regardless of quick time between mile-posts. The table of comparative speeds which he had submitted was constructed so as to show

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Note.—English and American Railroads compared, by Edward Bates Dorsey, M. Am. Soc. C. E., Transactions of the Society, Vol. XV, p. 1, January, 1886. Also Supplementary Paper, Vol. XV, p. 733, November, 1886.

The discussions on these papers occurred at several meetings.

the average speed between terminal and important stations, which really seems to be what is of most importance to the railroad traveler.

Capt. W. H. Bixby, M. Am. Soc. C. E., referred to methods of communication between passengers in English cars and the conductor or engineer; one was a bell-pull placed along the middle of the compartment, close to the floor; another was a bell-pull in the top of the car, placed in the partition between the compartments, and separated from the travelers by glass. There is a printed notice that, in case of accident, this glass should be broken and the bell pulled; in addition, there is a notice that if this is done without due cause, a severe fine will be imposed.

He also said, in reference to the second and third-class compartment cars in England, that there are great differences upon the different roads; some of the second-class cars being particularly good, and some of the first-class rather poor. The Midland Road has compartment cars of the lower grade well got up, and some of them as well upholstered as the first-class cars, the only difference being the number of seats put into the same sized compartments; in many of the first-class cars there are six seats, and in the third-class cars eight. In other respects the arrangements are as comfortable in one as in the other.

Mr. Dorsey replied that he had already mentioned the bell-rope on the floor, used on the London, Chatham and Dover Railway, and the electrical bell, used largely in France, but not to any great extent in England. Nevertheless he thought it safe to say that 95 per cent. of those who traveled in the United Kingdom cannot communicate with the engine driver or conductor when the train is in motion.

He could not agree with Captain Bixby that the third-class cars are as well got up, or that some of them are as well upholstered, as the first-class cars, and that the only difference is the number of seats put into the same sized compartments; his observation and experience had not led to this conclusion. The second and third-class compartments are made to seat ten instead of eight, and those compartments are smaller than the first-class; he had never seen the very comfortably upholstered third-class carriages alluded to.

O. Chanute, M. Am. Soc. C. E., referred to the remarks in the paper in regard to the matter of parliamentary expenses, and to the frequent allusions by persons in this country to those expenses as a great waste of money. He took a rather different view of this matter. It seemed to him that the parliamentary inquiries into the probable usefulness and economy of projected enterprises were a great safeguard against ruinous investments of money. And that, although during the last eleven years $35 000 000 have been spent in England merely in the inquiry as to whether projected roads should or should not be completed, there have probably been spent in this country during the same

length of time over $100 000 000 in injudicious enterprises. And that the time has probably arrived when we should be compelled to do what has been done in France and in England, that is to say, resolve to make careful inquiry into the necessity of proposed work before permitting schemers or capitalists to damage existing interests, to destroy the value of existing properties, or spend their money on parallel roads or duplicate enterprises where there are already sufficient facilities to do all the business. He called special attention to that paragraph in the paper stating that much of the business of the engineer in England consists in making careful inquiries and careful estimates of the probable value of enterprises before legislative sanction is obtained for their construction.

F. Collingwood, M. Am. Soc. C. E., said, in regard to the matter of parliamentary witnesses, that there were brought together on such occasions some of the best men in the engineering profession in the whole kingdom; that they have their offices near the Houses of Parliament; that this business is one of the best in the country; that only men of decided ability can secure such engagements, and the fees are really very large.

William Sellers, M. Am. Soc. C. E., thought that this question of parliamentary expenses had not been sufficiently considered. If, in comparing the cost, the parliamentary expenses are considered part of the cost of construction, then the English railways would show high construction costs, because they are short, and parliamentary expenses would therefore be large per mile; this, he thought, might seriously vitiate a comparison with the cost of completing our roads.

J. J. R. Croes, M. Am. Soc. C. E., thought that it would be interesting to know whether the parliamentary expenses in England are really larger than the legislative expenses in this country. In England there is one legislative center, but in the case of the trunk lines in this country there are a number of legislative centers. So far as he knew, there is no record kept of the expenses that a project undergoes in reaching the stage of actual construction, but he thought quite likely that the legislative expenses of carrying through any large project are about as great to the stockholders in this country as in England.

Thomas Egleston, M. Am. Soc. C. E., said that the parliamentary expenses were legitimate ones for the stockholder and bondholder, while in this country the money was often expended in improper methods of influencing legislation.

Mr. M. J. Becker, said that he thought the improper action in this country was often quite the reverse of what Dr. Egleston had suggested, and that the railroad companies were really the sufferers in instances where they should be protected by legislation.

Charles E. Goad, M. Am. Soc. C. E., said that it seemed to be considered here that English parliamentary expenses were wisely incurred with reference to the desirability of building a proposed railroad, but he thought that at the present time the very heavy expenses in certain cases were caused by the opposition of large existing corporations, in any case where there might be a fear of future rivalry.

Mr. Dorsey said that he thought it was a mistake to suppose that the arge sums charged to parliamentary expenses were for the purpose of ascertaining whether a proposed road should or should not be built, or whether it was or was not wanted, or whether it would pay or not; that part of the investigation was soon and cheaply disposed of. The great cost of the expenses generally comes from the opposition of some existing line, in the fear that its business might be injured by the proposed one.

A. M. Wellington, M. Am. Soc. C. E., thought that the writer of the paper was mistaken in saying that the vacuum brake was obtaining supremacy in England; there exists at present a great controversy between the advocates of the different brakes in England, and there is not the same nearly universal practice as here. Nearly all the different kinds of brakes are in use, but he thought that the one most largely adopted was the Westinghouse automatic, and that it was decidedly gaining ground over the others.

Mr. Dorsey said that by a recent publication of the Board of Trade of the United Kingdom, there was equipped on June 30th, 1885, 11 145 engines and cars with the Westinghouse brake, and 16 093 engines with the automatic brake.

Oberlin Smith, M. Am. Soc. C. E., said that one of the chief reasons why wider and more comfortable cars cannot be introduced in England is that the first coaches were built upon the stage-coach model, and that there is not now room between abutments and bridges and sides of tunnels for wider cars.

Mr. C. E. Goad thought that a longer experience in traveling upon English roads might have modified the opinions of the author of the paper as to various points. He thought that if the elevated roads of New York would adopt the method of opening their cars at the sides instead of at the ends, they would find it a great advantage. He believed that the trains on the underground roads in London could empty in one-third of the time taken to empty an elevated train in New York.

He thought the statement in the paper as to the lavatory accommodations on English trains was erroneous; there are very comfortable accommodations on nearly every train in England. Of course this is only on first-class cars; if you want to fare well you have to pay for it, just as you do in this country.

In reference to the movement of baggage, he thought that if the

English system were in use in this country it would be easier for the traveler than the present one; the baggage is in the same carriage with yourself, in a little van, and when you get out you give a porter sixpence and he gets your baggage and puts it on your cab. You can always get it at once, there is no delay; if you want to go to an evening party there is not a delay of one or two hours waiting for an expressman to come with your baggage. And the honesty of the men there is remarkable. Many Englishmen who have been away from their country for many years are fond of finding fault with everything English, but he did not propose to do so. It had just cost him quite a sum of money to get his baggage from Buffalo to Deer Park, where he was now stopping, and several hours' loss of time. In England there would have been no loss of time, and not one-third of the cost.

John Bogart, M. Am. Soc. C. E., said that a few years ago Baron Von Weber, then connected with the railway systems of Germany, visited this country to make a study of our public works. He was a man of decided opinions; one of these was expressed very strongly soon after his arrival, which was that the European system of handling baggage was very much better than the American. He traveled for some time in this country, and on his return to New York said that he thought our roads were in many respects not up to European standards, but that he had learned one thing, and that was that the only way to manage baggage was with the little brass checks.

Frederic Graff, President Am. Soc. C. E., said that he thought the advantages of the different systems were somewhat due to the different habits in regard to baggage in the two countries. In England a traveler generally has his luggage in hand parcels; the distances are not so great as in this country, and the packages are much smaller. Here large trunks are taken, and he thought that there would be considerable difficulty in putting an ordinary Saratoga trunk on the top of an average cab.

Captain O. E. Michaelis, M. Am. Soc. C. E., thought that one of the points affecting the methods of travel was that the European traveler was required, and seemed willing to yield up his personal liberty to the railroad, while in this country a first-class passenger would insist upon the privilege of going through the whole train. Switzerland is the only country in Europe where the American system is used.

Mendes Cohen, M. Am. Soc. C. E., Chairman of the Convention, thought that many differences in the methods of constructing and operating railroads in the two countries grew out of the fact that the development of the system here began when this was a sparsely settled country, and people were accustomed in moving about to take care of themselves. The tracks were laid and the cars started from the streets; people got on them in the most convenient way, and took such seats as

they could. As the railway system developed, the people have become accustomed to taking care of themselves, and it is now only upon our great roads that we begin to see the necessity of caring more thoroughly for the passenger. This also is shown in the progress of the construction of overhead and underground crossings.

In England, on the other hand, a densely populated country, all in authority were required at the first to look out for safety and life, and they paid attention to that rather than to anything else. The passenger who was to be carried was carefully put away and taken care of; he was quite willing to submit to it; he was as comfortable as in the old stage-coach and went at a higher speed; he had always put his luggage at the top of the coach, and why not on the top of the car? This was really a sort of necessity, because, as their lines developed, a car for a branch destination was simply shunted from the trunk line, and passengers, baggage and all went together; if the baggage had been on another coach there would have been delay and trouble. It seemed to him that the English system suits the English people better than ours would, and that when we find much inconvenience with their system, it is because we are not accustomed to it. When we are there it may take us some time to learn, but after awhile we do as they do and look out for some pleasant looking porter, give him a shilling and ask him to put our baggage in the right place.

Mr. Goad said, Oh, not a shilling, only a six-pence, you will ruin the country.

Mr. Cohen said he was afraid we had done it already.

Mr. F. Collingwood said that there was one important difference, not mentioned in the paper, between the railroads in the two countries, and that is, that at stations in England no person is allowed to cross the tracks. Some sad accidents had occurred at the place where he resides from this cause, and he thought that the English system ought to be introduced here.

Referring to the statement as to the unloading of coal, he said that he had seen cars unloaded in England by lifting up the whole car bodily and unloading it in that way.

There was one important item of cost in the running of English railroads, that is to say, if a fee of the right size is put into some official's hand a passenger can have the whole compartment to himself, the result being a great many cars for the number of people carried.

There is one trouble in regard to the baggage system in England which seemed to him important, and that is the necessity of carefully watching it at the different points. On three occasions he would have lost his baggage except for this personal supervision.

He thought that the distinction between the different classes of cars was comparatively nominal, and that the difference in price was really too great.

Dr. Egleston said that he thought there should be some recognition of the average honesty of the English employee. It is true that it is necessary to look after your luggage when you get into a train, and every time the train is changed, and you have also got to see whether your luggage is taken out of the van, whether your train changes or not; but he had a personal experience in regard to some lost baggage which had been left some miles back in a change of train, but which was recovered in a few hours, in a much shorter time, he thought, than lost baggage could be recovered in the United States.

Mr. J. J. De Kinder, C. E., said that in comparing the English and American systems, it should be noted that the short freight cars in England, on four wheels, handle freight much faster than we can with our long box cars. The cars there are so short that a good horse can handle them, while here we have to use a locomotive, and the locomotive is not always at the right spot. There the cars are moved from one track to the other without loss of time, and in the same way freight is taken on at local stations, as they would have one or two horses ready to move cars, while here we have to lose time in bringing up a locomotive.

As to the question of comfort in English cars, there certainly is an opportunity for difference of opinion; while it is true that there is only a can of hot water for warming purposes, and that may not sound very pleasant, yet in his experience of cars sometimes heated to 100 degrees Fahrenheit by steam, and then cooled off suddenly by the conductor's opening the door, and subjecting passengers to a stream of air 30 degrees below zero, he thought the comparison, so far as health is concerned, might not be without advantage to the English system.

Wm. P. Shinn, M. Am. Soc. C. E., referred to the subject of the introduction of overhead or undergound crossings, and to the fact that at several points, notably at Columbus and at Indianapolis, where tunnels had been constructed for the street traffic, only the street cars used the tunnels, and that was because their tracks were there; but that other vehicles and foot passengers cross on the street, keeping out of the way of trains as they best could, the lesson being that the only way to keep foot passengers and vehicles off the tracks would be to make a tunnel or bridge the only possible means of crossing.

Charles Latimer, M. Am. Soc. C. E., thought that a comparison of the number of men to the mile employed in the different departments of our railroads and those of Great Britain would disclose more additional information; he thought that there were many more employees upon the English than upon the American railroads. The percentage of the employees in the different departments of the New York, Pennsylvania and Ohio Railroad, with which he was connected, is as follows, the figures being very close approximations:

Transportation		42.8 per cent.
Locomotive Department:		
Shop	16.4	
Locomotive	12.2	28.6
Car Shops		9.5
Maintenance of Way		16.7
General Offices		2.4
		100.0

and the total number of men 4 200, or an average of 7.5 men per mile. The average amount paid per man is $50 per month; the average paid to officers and clerks is $100 per month.

J. Foster Crowell, M. Am. Soc. C. E., thought that the conclusions which Mr. Dorsey had reached supported the impression formed by most American railroad men when traveling on English railroads. The causes of the increased cost of operating which Mr. Dorsey suggests were doubtless potent, but would hardly account for the very great differences shown, and he thought that the question should be considered more deeply, and other features of English management looked at. It is doubly unfortunate that absolute data are lacking of the volume of traffic on the English roads, because the argument is based upon conditions to a certain extent assumed, and because, perhaps, the missing facts might be susceptible of classification and analysis to enable a distinct recognition of such causes. The limited researches he had been able to make led him to the opinion that the English roads do not preserve and utilize their records to the extent usual here, and this, if a fact, would be another cause of their failure to secure economy. The figures adopted by Mr. Dorsey as the average charges for passenger and ton per mile, are doubtless closely approximate; certain American railroads carry about twice the volume of freight that is carried by equivalent English roads, with a nearly equal number of passengers in each case, and therefore Mr. Dorsey deduces that the overcrowding on English roads is not a necessary condition, if it exists. It does not follow that the overcrowding may not be due to the constitution rather than to the volume of the traffic. Upon a relatively short line, frequent, light, low speed, short distance trains, with a comparatively small aggregate annual passenger mileage might interfere with freight traffic of whatever volume, while, on the other hand, an equal volume of passenger traffic carried on long distance, through, fast trains, judiciously grouped, might produce no sensible effect on the freight. In this country, other things being the same, the cost of operating mixed traffic is found to be greater on those parts of a line where the former conditions prevail, and these conditions exist to a greater extent on the six English than on the six American roads having the most traffic, selected by Mr. Dorsey for comparison of mileage. The remedy might be in trains of a greater capacity, and in a more complete separation of freight from passenger

traffic, and by additional tracks, especially approaching terminals and distributing points. Such provision is more difficult under the English system of construction than in this country. A considerable increase in the cost of movement of freight in England results from the mingling of all kinds of traffic at the terminals. The greater cost of repairs and renewals to locomotives should be accounted for by the primordial differences in the locomotives, irrespective of the difference in material or workmanship. Both the English and American engines of the present day are evolved types adapted to the requirements in each country, but the American had to be fashioned primarily to withstand excessive shocks and rough usage. The English road-beds are superior in conformation, rigidity and precision of grades; they are more perfectly aligned; their curvature is generally light and well adjusted, and they have a higher degree of rigidity in gauge and surface; but the employment of short rails, of rigid iron chairs, generally on every tie, the absence of that yielding which is a redeeming defect of an American track, produces a reactionary effect upon rolling stock that must be very injurious. While it is true that the average American track suffers from the violent impact of heavy engines, it is probably equally true that the English engine is unduly racked by the track reaction. Mr. Dorsey's figures show that the sums of the percentages of maintenance of way, and repairs and renewals of motive power are almost equal in the two countries, which seems an illustration of the axiom that action and reaction are equal. He thought that Mr. Dorsey had refrained from alluding to one general point of difference, which is noticeable in the handling and making up, switching, sorting and distributing of trains. In these regards the English practice seems unduly costly and inefficient to one accustomed to American methods. This is in part due to the greater number of vehicles, and the more complicated couplings and other appliances which take unnecessary time, but chiefly to the lower standard of intelligence, or at least of training, of subordinate officials and employees.

G. Bouscaren, M. Am. Soc. C. E., said that it was a subject of gratification that, on the whole, the comparison made by Mr. Dorsey as a result of his great labor in compiling so much valuable information, was favorable to the American system, but this implies a double obligation to be fair with our neighbors and co-workers. He thought that much might be said in defense of English engineers as to what appeared to be the excessive cost of their roads. In the first place, while the charters of American railroads generally cost but little, the preliminary formalities imposed by English law were a source of enormous expense. He presented the following, taken from the work of Mr. Ch. De Franqueville, Secretary of the Railroad Commission of France, on the "Public Works in England," showing the parliamentary expenses of eight railroad companies from 1848 to 1860:

Midland	$5 661 000
London and North Western	5 006 000
Great Western	4 137 000
South Eastern	2 756 000
Lancashire and Yorkshire	2 751 000
Great Northern	1 910 000
London and South Western	1 761 000
Caledonian	1 994 000
Total	$25 976 000

In connection with these expenses, Mr. De Franqueville says: "Four different companies competed for the concession of the line from London to Brighton, and spent in one year in parliamentary fees over $500 000. They were represented by twenty ordinary advocates, six sergeants, or Queen's counsels, twenty solicitors, and a strong battalion of parliamentary agents, experts, engineers, etc. A short time afterwards the Trent Valley company spent $737 000 trying to secure the concession of the line from Stone to Rugby and did not succeed. The Great Northern bill, presented in 1845, cost the company $3 853 000 for a line 245 miles long, being at the rate of nearly $16 000 per mile." A careful estimate made by the same author of the average price paid by railroad companies in England for right of way not occupied by buildings, was $1 070 per acre; to this must be added a very large amount for "damages." It is quite clear that the cost of these two items alone, namely, Parliamentary expenses and Right of way, which are entirely beyond the control of the engineer, is not far from the cost of an average American railroad.

Very few lines are now being built in England, and new construction is almost exclusively limited to short branches and connections. But at the time when the greater part of the lines were built the ordnance maps were incomplete, surveying parties could not go over the ground without the consent of the land-owners, and their consent was often refused, owing to prevailing prejudices. Observations had often to be made at night, or on Sunday during service hours when the proprietors were not at home. Various artifices and stratagems were indispensable for securing necessary information to prepare the very accurate plans required. It can be imagined how much more costly location under such conditions must have been as compared with that of our American railroads.

No fair comparison can be made of the cost and styles of construction in the two countries without taking into account the great differences of conditions under which the work was done on each side. While the English Government has no standard specifications, the apparent latitude given to the engineer is in effect very much restricted; first, by laws regulating all classes of road crossings, limiting the radius of curves to a minimum of 2 640 feet, and investing the Board of Trade

with further regulating powers which are left practically to the discretion of its inspectors; secondly, by the sharp competition which every railroad bill must invariably fight before parliamentary commissions, which opens the door to criticisms more or less reasonable, but generally supported by expert testimony and often passed upon by men more experienced in debates of politics than in the art of engineering. The result being that the highest character of work is as a rule not a matter of choice, but one of obligation with the English engineer. After being hampered in the selection of the most favorable location by the large question of land damages, the English engineer may be forced against his better judgment to spend much money for a show of security for which no direct compensation in economy or operation can be expected.

On the other hand, American engineers enjoy all desirable freedom in locating their lines and preparing specifications, but are often compelled to sacrifice economy of operation for the want of capital. These contrasting circumstances have worked altogether to the advantage of American railways. If necessity is the mother of invention, one cannot imagine a better field for discoveries in the adaptability of means to results than the condition which obtained at the incipiency of railroad construction in this country. Had American engineers been saddled with the same impediments, and blessed with the same abundance of capital, it is not improbable that we would have done very much as they did in England.

Referring to the remarks of Mr. Dorsey comparing the cost of construction and operation in both countries, the same being:

For England per mile	Construction	$202 227
	Operation	10 000
For the United States per mile	Construction	62 176
	Operation	4 410

and the percentage of annual expenditures that is affected by good or bad construction having been found to be eight per cent. greater for the United States than for England, the author concludes as follows:

"If all the railroads in the United States had been as well constructed as in England, that is, at an additional cost of $140 051 per mile, there would have been saved eight per cent. of the annual operating expenses, which average $4 410 per mile. Eight per cent. of this amounts to $353, which would have been the amount saved by expending $140 051 more per mile; this equals 0.25 per cent. on the additional cost. In other words, it would have required an additional expenditure in construction of $140 051 per mile to save annually $353 in working expenses. On the other hand, if the English roads had been built on the American plan at $140 051 less cost per mile, their working expenses would have been increased eight per cent, or $800 per mile annually. To save this, $140 051 has been expended per mile."

Mr. Bouscaren said that it did not follow from the fact that English roads did cost $140 051 per mile more than American roads, that American railroads would have cost $140 051 more than they did if they had been built as well as the English, on the contrary, it is quite evident from the author's own figures that they would not. Also that it is difficult to see what parliamentary expenses, the cost of the right of way, the large expenditures for road crossings, and the interlocking system of block signals prescribed by the Board of Trade, and which enter for a large proportion in the surplus cost of English railways, have to do with the saving of operating expenses. The block system and the numerous road-crossing bridges are, on the contrary, a source of much additional expense for maintenance. The conclusions drawn by the author from this comparison are therefore misleading. Nothing is more adverse to correct results in all branches of scientific investigation than reasoning on generalities without a proper analysis of the subject. Engineering is not an exception to the rule, and the question of the cost of construction of a railroad in its bearings on the cost of operation is particularly one of great complication; it requires, as a preliminary, that under both headings of "construction" and "operating expenses," a careful classification should be made of all parts correlated to each other. In the absence of the necessary data for such classification, either for the American or English railroads, no fair comparison can be made between them with regard to the question as to how far the engineers were justified in their expenditures for construction.

He thought it beyond discussion that for important roads it generally pays to build permanent instead of temporary structures; to provide a thorough rather than an insufficient drainage for the road-bed; to have a well ballasted track and a weight of rail proportioned to the traffic. The question of distance, curvature and grade is not so simple, being dependent in a very large measure on the volume and character of the traffic. Between two possible locations for a road, the elements of cost, distance, curvature and grades must be equated to find the relative value of the two lines, and according to the quantity and character of traffic assumed as a basis for comparison, one or the other line may be found the most profitable to build. The cheaper line, even with greater length, steeper and longer grades and curves, may be found to give the largest returns for the capital invested, with a light traffic at high rates, and the reverse may be the case for a heavy tonnage at low rates. In making such comparison he ventured to say that scarcely two engineers could be found who would attribute the same coefficient of value to the different elements of distance, grade and curvature. This only proves the lack of reliable data as to the influence of each on the cost of operation, and this penury of information in its turn comes from the extreme difficulty, in all experiments that have been made on the subject, of apportioning correctly to each cause the wear and tear and consumption of

power attributable to each. This subject will always remain a useful field of investigation, especially in this country, where it will often occur that lines cheaply constructed at first can profitably be changed or improved after a time to meet different conditions of traffic.

In comparing maintenance of way expenses, it must be borne in mind that on English railways a much larger amount is spent for "fancy work," having no direct bearing on the safety and economy of operation, than on American railroads. He does not agree with the author as to the general proposition that severe winters are necessarily a cause of larger expenditures; his experience is rather to the contrary, that a mild and wet winter is a source of greater expense than a very cold one. A very large proportion of maintenance of way expenses is entirely independent of the traffic, depending solely on the physical conditions of climate, weather, topography and character of the material forming the road-bed and structures. On the Cincinnati Southern Railroad, where nothing was spent for fancy work, this proportion was 52 per cent. in 1884.

Referring to the motive power and rolling stock, Mr. Bouscaren says that this seems to be the weakest part of the English system. The comparative figures and tables given by the author show to a surprising degree that the American locomotive hauls more tons of freight and more passengers, runs a greater distance, and costs less for fuel and repairs than the English engine, whilst with the easier grades and curves and the better track of English roads the reverse should be the case. This should certainly be a matter for serious consideration, Mr. Bouscaren thinks, by English engineers and managers. There cannot be a great difference in the efficiency of the English and American locomotives, considered as steam motors. The greater speed of English freight trains and the greater proportion of stops at way-stations, explains only a part, he thinks the smaller part, of this great disparity of results; the principal cause is to be found in the advantages to the American system derived from the universal application of the bogie truck.

Mr. Bouscaren agrees with the author that neither of the two systems is perfect in itself, and that each can profitably borrow from the other. He thinks that as a rule we are perhaps too slow in following up the growth of traffic on our main lines with permanent improvements. That probably a great many roads which are now earning just enough to pay expenses and interest, could, by the judicious expenditure of more capital in the replacement of their wooden trestles and bridges with permanent structures; in a better ballasted track and heavier rails; in better drainage and protection of their road-bed; save enough on their maintenance of way expenses and cost of transportation to pay a small dividend to their stockholders. He also thought a better system of inspection and test of materials and supplies very desirable. We were very far behind England in this respect, and the saving of money

arising from the purchase of inferior rails alone would be sufficient to change many annual balances from a deficit to a surplus. Referring to the application of the compound system to locomotives, the favorable results obtained on the London and North Western, and on several of the French and German lines, are a test of its practical value.

Mr. Bouscaren does not agree with the author in advocating the indiscriminate application of the block and interlocking system to all our roads in imitation of those of England. The absolute block would be impracticable on most of our single track roads, as long blocks would very much reduce the capacity for traffic on many, and the cost of the plant and expense of operating blocks of such length as would accommodate the business would be entirely beyond the means of most of them. From the statistics of killed and wounded in both countries given by the author, it does not appear that the traveling public and employees enjoy a greater immunity from accidents in England than here.

As to the parliamentary expenses, etc., he thought it scarcely to be hoped that the conservative methods of England will admit of such reform being made in its government regulations as will save the roads that are yet to be built from the great burden of parliamentary and other unprofitable expenses, but thinks that there is ample room for improvements in other directions. If it will not pay them to increase the width and head-room of their tunnels and bridges to admit of larger cars being used, they can surely add to the comfort and security of their passengers by a different internal arrangement that will provide toilet accommodations; communication with the conductor and with each other; a better system of heating and ventilation; and more liberty of motion, a privilege highly appreciated by any one engaged on a long journey. Also that the check system for baggage should be adopted by them on the ground of comfort and economy.

As to the extraordinary method described by the author as being used to supply brake power on heavy trains, he thought it undoubtedly an abnormal remnant of the past, which is likely to be soon superseded by one of the several good systems of automatic brakes now in successful operation here. The ability of the bogie truck to keep the track at high speed is no longer a subject of controversy or doubt by any one connected with American railroads; its general introduction in England would mark a golden era in railway operation in that country, and that is only a question of time; when it is done he thinks that the greater part of the extraordinary difference in "locomotive charges" and "repairs of carriages" in the two countries will disappear. He thought, however, that it is clear that with their own thorough construction and all our improved appliances combined, the railroads of England must remain inferior to those of America if their value as such is measured by the cost of transportation; in other words, the cost of transportation in England will always be greater on account of the enormous capital

expended on parliamentary requirements without adequate results in the economy of operation. The advantage which England possesses now in cheaper material and labor is decreasing every day by the gradual equalization of the prices of labor in the two countries and the rapid development and improvement of our mining and manufacturing industries. Coal is already as cheap here as it is in England, and Mr. Bouscaren thinks the day is probably not far distant when iron and steel will also be.

Mr. Dorsey said that Mr. Bouscaren was mistaken in thinking that the author blames the English engineers for the great cost of the English railroads; he merely gave the facts as they exist, without blaming any one. Mr. Bouscaren, in common with many others, over-estimates the importance of land damages, right of way, and legal and parliamentary expenses in making up the total average cost of $202 227 per mile. The highest estimate given for the average cost of land per mile is $20 000; add to this the $16 000 (which is given by him as an example of excessive charges) as the average cost per mile of the Great Northern in parliamentary expenses. Take this as the average of all English roads, this gives:

Average cost of right of way and damages.....	$20 000
" parlimentary and legal expenses.....	16 000
Total per mile.....	$36 000

Leaving $166 000 as the average cost of construction per mile, which is very high. Considering the low price of labor and materials, the cost is much greater than ours, including everything.

George Downe, M. Am. Soc. C. E., said, by letter, that he had hoped to prepare a comparison of the railways of the Australian colonies similar to those made by Mr. Dorsey, but he found that the reports of the colonies would not allow of comparison at all points in the manner desired. It appeared to him that Mr. Dorsey's comparisons were erroneous, in that, in Table No. 53, for instance, of Mr. Dorsey's paper—the basis upon which the comparison is made is the percentage cost of items on total operating expenses—any comparison in this form can hardly be otherwise than of an erroneous and misleading nature. It does not follow because a certain service is performed in America at a smaller percentage of the cost upon total operating expenditure than in England, that the result has necessarily been secured by better management and by the practice of more rigid economy. If under any certain head of service the expenditure is a fixed amount, then as the other items which make up the total operating expenses are high or low in cost, so also must the percentage of the particular item be affected. For instance, suppose that on a railway line in Australia the operating expenses amounted to £100 000, and of this sum the wages of drivers

and firemen cost £10 000, the percentage would of course be 10; but if the same item at English rates should cost £5 000, the percentage on total expenditure would not be 5, because the item being reduced by £5 000, the total expenses would be reduced by the same amount, so that £95 000, instead of £100 000, would properly represent the total, and the percentage on that amount would be $5\frac{3}{10}$. In the calculations submitted in Mr. Dorsey's Table No. 53 he has lost sight of this fact, and in showing what the percentage cost of wages of drivers and firemen would be in America if English rates obtained, he has simply reduced by one-half the actual percentage worked out on American cost, because English rates are 50 per cent. lower, overlooking the fact that if the items were obtained at half the American cost, so would the total operating expenses be reduced. To work out the percentage of the English cost of an item and include that item in total operating expenses at the American cost, certainly places the working of the American roads in a favorable light at the expense of the English companies.

Suppose that in America the wages of drivers and firemen were reduced to English rates, would not the cost of all other labor fall in the same proportion, and would not this reduce total operating expenses throughout, increasing the percentage cost of wages of drivers and firemen on the total operating expenses? Undoubtedly this would be so, and any item of cost included in total operating expenses would affect the percentage cost of another item, making it high or low according to the prices paid. This same method has been followed in Mr. Dorsey's tables showing the percentage cost on total operating expenses of fuel and of repairs and renewals of locomotives, and only erroneous deductions can follow. For instance, a railroad in America costs, say for one year, total operating expenditure of £500 000; of this sum the cost of fuel is £50 000; wages of drivers and firemen, £25 000; renewals of locomotives, £15 000, which would give the percentage cost three items, as 10, 5 and 3. Now, suppose that in England the same line pays £20 000 for its fuel, but exactly the same amounts for wages of drivers and firemen, and repairs and renewals of locomotives, and at the same time obtains materials for carriage and wagon repairs, and the labor in connection therewith, at rates sufficiently low to reduce the total operating expenses a further sum of £30 000, the total operating expenditure on the English line would be £440 000, and by computing the percentage cost of the items under consideration, the result would be, fuel, $4\frac{5}{10}$; wages of drivers and firemen, $5\frac{7}{10}$; repairs and renewals of locomotives, $3\frac{4}{10}$. Here we have two lines paying exactly the same amounts for wages of drivers and firemen, and for renewals and repairs of locomotives, yet, comparing their operations on the basis of percentage cost of total operating expenditure, the American line appears to be much less than the English, and it is in this form that the comparisons are submitted by Mr. Dorsey.

TABLE A.—Australian Government Railways.

Some particulars as to the work performed, and the operating expenses incurred during the year 1884, as gleaned from the reports published by the different colonies.

Name of Colony.	Average miles of railway line operated in 1884.	Total operating expenses.	Total tonnage hauled one mile. (Load and rolling stock.)	Cost of Locomotive Branch.		Cost of Traffic Branch.		Cost of Ways and Works Branch.		Cost of General Charges.		Results.			Average gross tonnage hauled over every mile of line operated.
				Total amount.	Cost per gross ton per mile.	Total amount.	Cost per gross ton per mile.	Total amount.	Cost per gross ton per mile.	Total amount.	Cost per gross ton per mile.	Working expenditure per gross ton per mile.	Receipts per gross ton per mile.	Profit per gross ton per mile.	
		£	Tons.	£	d.	£	d.	£	d.	£	d.	d.	d.	d	Tons.
New South Wales	1 432	1 301 259	1 087 562 219	509 554	.1124	310 211	.0139	367 317	.0811	44 107	.0100	.29	.46	.17	759 471
Victoria†	1 655	1 277 425	*	492 627	....	442 722	....	281 475	....	60 601	....	...	...	...	.....
Queensland.....	1 123	357 535	215 816 715	119 683	.1331	11 502	.0895	157 350	.1750	.....	....	.40	.76	.36	192 179
South Australia‡.....	1 013	372 187	202 532 339	136 103	.1612	106 367	.1265	106 422	.1261	16 018	.0190	.44	.66	.22	201 927

* No information in report from which this information could be ascertained.

† Services of Railway Commissioners not included in the Victorian report of total expenditures.

‡ Exclusive of cost of horse power used on tramways, and inclusive of the above.

TABLE B.—Australian Government Railways.

Some particulars of the ton mileage, load and rolling stock, with the proportion of dead weight hauled to load carried.

Name of Colony.	Weight of Load Carried.			Ton Mileage of Load.			Ton Mileage of Rolling Stock.			Gross Ton Mileage.	Proportion of Dead Weight Hauled to Load Carried.		
	Coaching.	Goods.	Total.	Coaching.	Goods.	Total.	Coaching engines and carriages.	Goods engines and wagons.	Total.	Weight of load and rolling stock hauled one mile.	Coaching.	Goods.	Total.
	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.			
New South Wales	765 014	3 124 425	3 889 439	11 591 674	169 555 989	181 147 663	293 566 711	612 867 845	906 614 556	1 087 569 219	25.32	3.62	4.90
Victoria*	2 367 352	2 272 361	4 639 713	No information in report to admit of these particulars being submitted.									
Queensland*	69 737	408 635	478 372	†	†	†	†	†	†	‡215 816 715	....	....	....
South Australia§ .	276 403	955 973	1 232 376	3 469 649	31 795 322	35 264 971	79 713 597	87 554 671	167 268 268	202 533 239	25.	2.75	4.74

* Only the number of passengers given in the reports of the railways of Victoria and Queensland. The tonnage of load carried has been estimated by allowing the usual number of passengers to the ton, and for the balance of coaching traffic taking the same proportion or ratio as experienced in New South Wales.

† No sufficient information in report to admit of these particulars being ascertained.

‡ The weight of each engine in steam is given, and the average weight behind tender is also published. From this source the gross ton mileage, vehicles, and load have been computed.

§ Tramways included in South Australian reports; and, from the way in which the returns and accounts are submitted, it is not possible to accurately separate the railway and tramway traffic.

TABLE C.—Australian Government Railways.

Particulars as to the length of line operated; the rolling stock in use; the average weight of same per vehicle; and the train mileage run during the year 1884.

Name of Colony.	Gauge.		Average length of line operated, 1884.	Rolling Stock Used in Traffic.				Average Weight of Rolling Stock.			Train mileage.
				Number of engines.	Number of coaching vehicles.	Number of goods vehicles.	Total pieces of rolling stock.	Engines.	Coaching stock.	Goods stock.	
	Ft.	In.	Miles.					T. c. q.	T. c. q.	T. c. q.	
New South Wales	4	8½	1 432	336	776	6 938*	10 345	52 15 1	8 15 0	5 0 2	6 403 041
Victoria	5	3	1 655	305	702	4 797	5 804	†	.....	.....	6 849 818
Queensland	3	6	1 123	125	142	1 865	2 132	19 17 0	‡	.....	2 192 454
South Australia	3 5	6 3	1 003	118	222	2 980	3 320	34 10 0	7 15 2	3 11 1	1 732 716 ‖

* Also 2 295 private coal trucks.

† No information relative to the weight of rolling stock is given in report of Victoria.

‡ No information relative to the weight of rolling stock other than locomotives is given in report of Queensland.

‖ Tramways included.

TABLE D.—Australian Government Railways.

Particulars of the principal items of locomotive expenditure incurred during the year 1884.

Name of Colony.	Total operating cost.	Total tonnage hauled one mile (load and rolling stock).	Cost of Fuel.		Wages of Drivers and Firemen.		Cost of Repairs and Renewals of Locomotives.		Cost of Repairs and Renewals of Carriages and Wagons.		Total Running Cost.		Total operating expenses of locomotive branch.
			Amount paid.	Cost per gross ton per mile.	Amount paid.	Cost per gross ton per mile.	Amount paid.	Cost per gross ton per mile.	Amount paid.	Cost per gross ton per mile.	Amount paid.	Cost per gross ton per mile.	
	£	Tons.	£	d.	£	d.	£	d.	£	d.	£	d.	£
New South Wales	1 301 259	1 087 562 219	83 258	.0183	128 931	.0284	95 067	.0210	79 833	.0176	296 169	.0653	509 554
Victoria	1 277 435	*	124 532	....	102 782	.....	91 435	.....	7744	.....	305 554	.....	492 627
Queensland	359 535	815 816 715	†	....	.....	.....	.....	.....	.....	.....	.....	.....	119 683
South Australia‡.	372 187	202 533 239	37 394	.0443	23 306	.0271	25 124	.0200	22 261	.0264	110 555	.1310	136 183

* No information in report to admit of this information being ascertained.

† The particulars relative to the expenditures of the locomotive branch in Queensland are confined to the following brief entry:

Locomotive working.—Salaries, wages, fuel, etc..... £ .....

Stores .....

Total..... £ .....

‡ Exclusive of cost of horse power on tramways.

In New South Wales the cost of holidays and sick pay to employees are not included in the wages cost shown under the different services, but are shown to separate schedules; in the other colonies, however, these items would appear to be included under the general head of "Wages."

In South Australia all wages incurred in "running" are shown under the head of "Running wages." The amount shown to drivers and firemen in this return has been arrived at from the information afforded in a detached statement published in report showing number and classification of all employees in locomotive branch during the year. The wages of cleaners, pumpers, coalmen, etc., being computed from the daily rates and deducted from the total amount of "Running wages," the balance gives the wages of drivers and firemen. The wages of coalmen has been computed and added to the fuel cost, because in the other colonies this item is charged to cost of fuel. In New South Wales the average daily rate of pay of a driver is 15s. 1d. per day, and of a fireman, 9s. 1d., as against 11s. 8d. and 5s. 4d. respectively, in South Australia. Victoria and Queensland omit all information as to rates of pay to employees.

In the absence of any direct information as to the actual ton mileage of the English railways, Mr. Downe was inclined to receive the figures of the paper under discussion with much caution. Doubtless the different systems of keeping account of returns adopted by the different railways, present serious and perplexing difficulties in the way of an impartial comparison between the railways in the different parts of the world; and unless very careful discrimination be exercised in analyzing the different systems and accounts, erroneous conclusions are almost sure to be arrived at. It appeared to him that the only true basis of comparison is the ton mileage, and the sooner railway companies all over the world come to recognize the value of this, the better will it be for placing on record lucid and reliable information. The ton mileage of load carried, coach and goods separately, should be compared with the ton mileage of the rolling stock used in its transition, with the object of ascertaining the haul to the load carried, a most important consideration, and the expenditure in working under each particular head of service, with the gross tonnage moved over the rails. By this system of comparison the actual work performed can be seen at a glance, and were the different railroads to furnish particulars of their operations in this form, with a knowledge of the road, as to its length, gradients and curves, it would be easy to properly estimate the nature and extent of the work performed and the working cost incurred.

It will be seen by some tables sent herewith, that in Australia the diversity of the systems whereby particulars of railway operations are placed before the public is somewhat astonishing. But he had no doubt the same diversity would be found in America and in England. He regretted that he had been unable to obtain such reports for the other colonies.

In the New South Wales reports, very full and lucid statements are given as to all details of railway operation. In the tables presented herewith it will be seen that the report of railway operations in South Australia more closely approaches that in New South Wales in completeness; but, unfortunately, the operations of the tramways are included in the railway returns, and in such a form as to prevent the separation of items under the respective services. The report of Victoria is anything but satisfactory; the goods and passenger train mileage are not shown separately, nor weights of rolling stock given; the number and classification of employees, with rates of pay, are omitted; no information is afforded as to ton mileage, and the mileage run by each engine is not furnished; nor is a detailed statement as to the condition of locomotives and rolling stock available.

The Queensland report is voluminous, and might have been more condensed. There is no information as to ton mileage of coach and goods traffic; nor is the train mileage coaching and goods shown separately. Particulars as to rates paid in wages are omitted. In order that

some comparison relative to the working of the Australian railways may be secured under the system advocated, the tables submitted herewith have been prepared, and it is thought that they speak for themselves without detailed explanation. The incomplete returns of the Victoria railways, unfortunately, throws that colony almost entirely out of the comparison; and, considering the extensive nature of railway operations in Victoria, it is greatly to be regretted.

Robert L. Harris, M. Am. Soc. C. E., asked what was probably meant in Table "B" in the column headed "Proportion of dead weight hauled to load carried." For instance, the figures 3.62, under the heading of "Goods," he thought meant there was 3.62 times as much vehicle as load.

Mr. A. M. Wellington said that the usual proportion in this country is 7 tons of load to 10 tons of car. These Australian figures would indicate something less than 3 tons of load to 10 tons of car.

Mr. E. P. North said that if the figures in the table in reference to coaching were correct, they would have 2½ passengers to an average Pullman car.

H. Stanley Goodwin, M. Am. Soc. C. E., thought that the figures 3.62 were correct, and that the fact stated was that the dead weight is 3.62 times the load; he knew that we obtained much better results in this country; the average weight of cars in general use here will come to a little more than half the capacity of the car. A car of 30 000 pounds capacity will weigh a little more than 15 000 pounds. In the coal traffic the car is fully loaded one way, and comes back empty, in this way you have 40 000 pounds load one way and when hauling the cars both ways you get 40 000 pounds of car. The coal tonnage, of course, is exceptionally good, but the general tonnage for freight would average something like that. The result given for Australia shows a great deal more dead weight carried in proportion to the load than is the case in this country; the attention of our Members in Australia should perhaps be called to this fact.

Mr. Edward P. North presented figures obtained in reference to freights in England from the report of Sir Bernard Samuelson, made to C. M. Norwood, President of the Association of the Chambers of Commerce of the United Kingdom. Complaints having been made by some one in Great Britain that the freight charges were too high, Sir Bernard Samuelson gathered carefully this information in regard to rates on railways in Germany, Holland, etc., and compared the charges with those on the English roads. In the tables submitted herewith, the rates so obtained for the roads in Great Britain are compared with the present trunk line rates between Chicago and New York, which had been given to Mr. North by Mr. S. F. Pierson, of the Trunk Pool Commission.

Attention was called to the fact that though the distance between Chicago and New York varied by different routes from 912 to over 1 100 miles, all the rates, being equal, are computed for a distance of 1 000 miles; and also the fact should be noted that the distance hauled here is much greater than in England, giving a larger divisor for terminal expenses; on the other hand, it may be noted that the volume of traffic is greater in England than in this country.

TABLE SHOWING FREIGHT RATES ON ENGLISH AND AMERICAN RAILROADS.

All the rates are given in mills per ton mile. The pound is valued at $4.84

		English.	Amer.
PIG IRON.			
Barrow to Sheffield	122 miles	14.5	5.
" Birmingham	161 "	16.	5.
IRON WIRE, PACKED AND UNPACKED.			
Birmingham to Coventry	19 miles	110. and 63.6	7.
" Manchester	84 "	49. " 30.	7.
" Liverpool	97 "	46.9 " 30.	7.
" London	113 "	50.3 " 32.4	7.
" Hull	132 "	46. " 32.	7.
" Glasgow	286 "	29. " 22.5	7.
HARDWARE.			
Birmingham to Manchester	84 miles	51.	12.
" Liverpool	97 "	48.3	12.
" London	113 "	50.5	12.
" Plymouth	222 "	41.	12.
" Glasgow	286 "	31.	12.
" Edinburgh	298 "	26.6	12.
SAWS AND TOOLS.			
Sheffield to Hull	53 miles	59.4	12.
COTTON YARNS.			
Manchester to Hull	92 miles	47.4	15.
" Newcastle	142 "	39.2	15.
COTTON GOODS, EXPORT AND HOME.			
Manchester to Liverpool	31 miles	53.2 and 82.	15.
" Hull	92 "	47.	15.
" Birmingham	84 "	61.	15.
" Bristol	117 "	42.3	15.
" London	200 "	25.5 and 43.9	15.
" Exeter	266 "	39.7	15.
WOOLEN, WORSTED AND STUFF GOODS.			
Bradford to Manchester	40 miles	87.	15.
" Birmingham	120 "	58.3	15.
" London	196 "	48.7	15.
" Glasgow	210 "	47.2	15.

EARTHENWARE AND CHINA. NOTE TRUNK LINE RATES.

China, 15; earthenware, 7 mills per ton mile.

Stoke to Birmingham	45 miles	53.7 and 77.	15. and 7.
" London	150 "	31. " 50.	15. " 7

General Machinery, Export and Home.

	English.	Amer.
Leeds to Hull	51 miles 59.2 and 118.5	7.
" Newcastle	100 " 27.8 " 34.3	7.

Agricultural Machines (Iron), Export and Home.

Banbury to London	78 miles 80. and 93.	7.
Bedford "	50 " 90.4 " 106.4	7.
" Liverpool	152 " 65.8 " 86.	7.

Sugar.

Liverpool to Manchester	31 miles 85.8	5.
Hull to Sheffield	53 " 53.	5.
London to Northampton	67 " 39.	5.
" Sheffield	162 " 22.4	5.
Greenock to Newcastle	186 " 17.	5.

Cotton.

Liverpool to Manchester	31 miles 56.	5.4

Wool.

Liverpool to Manchester	31 miles 71.	9.

Tea.

Liverpool to Manchester	31 miles 84.5	15.

Oranges.

Liverpool to Manchester	31 miles 71.6	12.

Tallow.

Liverpool to Manchester	31 miles 61.7	6.

Bacon and Ham.

Liverpool to Manchester	31 miles 71.	6.

Grain and Flour.

Liverpool to Birmingham	97 miles 31.	5.
Bristol "	94 " 20.	5.

The first price, where two are given in the English rates, is for goods to be exported.

The American rates given in this table should be multiplied by $\frac{112}{100}$ for exactness of comparison, because the English rates are on gross and the American on net tons. For example, the rate as given from Liverpool to Birmingham, 97 miles, on grain and flour, is $3.01 per gross ton, and the rate as given from Chicago to New York, 1 000 miles, is $5 per net ton and $5 60 per gross ton. It will be noticed that the average of the American rates here given are 8½ per cent. of the average English rates.

In this connection it would be of interest to know if the British rates are ever "cut," and to what extent freight cars are allowed to stand on private side tracks for the convenience of shippers and consignees. As has been shown here, railroads sometimes allow consignees to retain freight cars for a week or more without extra charge.

In England getting a railroad charter is a very difficult and expensive

proceeding. It requires parliamentary proceedings, with a high class of parliamentary engineers and lawyers, which we understand are expensive luxuries; the result is that the few railroads in the country have in reality a monopoly; they have formed a strong pool among themselves; they do not compete in prices. The general public pays for this. Here we get low rates because by our general railroad laws competition is more active than in any other country. He thought that the rates here were, taking them all through, not more than one-half, or perhaps one-third of those in England, which are the highest in the world. He also thought that we have better railroad men than in England; that our locomotives run more miles and haul more freight at a smaller cost for repairs. We put comparatively a small capital in our roads, and, as Mr. Dorsey says, it is profitable to open a road on a small expenditure of capital, improving it afterwards when the rates will be lower. He called attention to the fact that the rates given for trunk lines in the table are the published American pool rates; nobody supposes that the companies ever get more than these published rates; they are sometimes accused of taking very much less.

Mr. A. M. Wellington said that he would like to inquire of Mr. North whether the English rates which he had read were not gotten up by some one anxious to make them appear as high as possible, and who therefore went through all the rates to pick out the big ones.

Mr. E. P. North replied that the rates were professedly gathered to influence legislation in England, and that he knew of few higher; they are in fact mentioned as the maximum rates; at the same time notice should be taken of the fact that they are between the principal manufacturing and commercial centers of the country, and therefore may be considered as governing rates in the transportation of the country.

Mr. H. Stanley Goodwin thought that if they were any higher they would have to take the goods in part payment for the freight.

W. Howard White, M. Am. Soc. C. E., said that Mr. Dorsey had expressed an opinion in favor of steel ties, thinking that they might be more economical under certain conditions, and he asked Mr. Dorsey whether he knew how long the metal ties would last.

Mr. Dorsey said that he had seen some that had been down five years and they seemed to be perfectly good. It is claimed that by Dr. Angus Smith's coating they are perfectly protected against rust, and the jar of the trains does not seem to affect this coating. Of course, where a good tie can be bought for sixty cents, he did not think the metal ties would be as cheap. In England the creosoted ties are largely used; the holes for the spikes are first bored, and after all work on the tie is done, the creosote is applied. He thought that by this process the life of the tie was prolonged for four years.

Mr. W. Howard White said that he had made some figures in reference to the comparative cost of different ties, assuming the fund for replacing as being at compound interest at 4½ per cent.; these figures are as follows:

Georgia pine (assuming the ties to last eight years), first cost, delivered in New York	$ 70
Hauling and laying	20
Fund to replace every eight years	2 13
Total	$3 03
Steel ties (8 feet long by 10 inches by ⅝ inch cross-section, same to last fifty years) first cost at 1⅛ cents per pound	1 80
Laying	20
Fund to replace every fifty years	25
Total	$2 25
Preserved hemlock (to last twelve years), first cost, with laying	78
Fund to replace every twelve years	1 12
Total	$1 90

Thus we have:

Preserved hemlock	1 90
Southern pine	3 03
Steel	2 25

M. N. Forney, M. Am. Soc. C. E., thought that Mr. Dorsey was mistaken in saying that in England account was not kept of the ton mileage. In the early part of his paper there is an estimate made of the cost per ton per mile. If it is a fact that the ton mileage is not given by the English roads, he could not see how the writer of the paper could get at the cost per ton per mile. If the ton mileage is not known, then the figures given with reference to the cost per ton per mile were merely shrewd guessing, therefore unreliable.

Again, he referred to the fact that Mr. Dorsey called attention to figures taken from the report of the Railroad Commissioners of the State of New York, but a study of those reports could not fail to show a lack of precision, particularly with reference to comparisons. The New York Central Railroad, for example, he supposed was obliged to report its expenses for fuel, but that road did not keep an account of the cost of fuel used on locomotives unless in the aggregate purchases of coal made for the whole line of the road. The figures therefore given in the State Commissioner's reports must be taken with a large grain of allowance.

In relation to the efficiency of locomotives, when it is attempted to make a comparison of the cost of fuel in proportion to the service performed, the great difficulty will be at once met with of finding any

correct measure for such a comparison. Even assuming that you have two roads running side by side, it is difficult to get any exact measure of the work done by different locomotives. Taking this into consideration, he thought that these figures could not be depended upon as presenting the actual differences of cost for these services in England and America.

In regard to the comparison of English and American locomotives, undoubtedly the English locomotive is adapted for use in that country and it is a very efficient machine. On the other hand the American locomotive has been adapted to use here. One of the chief differences in the locomotives is that the English use inside cylinders and we outside cylinders; they use plate frames and we use bar frames. There can be no doubt that so long as the English people use the short rigid wheel-base for their locomotives it makes their engines unsteady to use outside cylinders, but if they used a truck and lengthened the wheel-base that defect would be remedied. The English, not having had experience with outside cylinders, did not attach them so as to give that stability which we know is required, and, as a result they worked loose, which led the English to abandon them. In this country we have had so much experience with outside cylinders that we have learned to fasten them securely, and engines with outside cylinders do not shake themselves to pieces here. He thought that the argument was in favor of the American type, and that if a fair trial was given it, it would be found equal in efficiency and less expensive to maintain than English engines are.

Mr. A. M. Wellington regretted that he had to disagree to some extent with Mr. Dorsey's views in reference to the differences in expenses as stated by him. In comparing in this way by percentages, things are compared which cannot well be compared with each other; the English roads have short tracks and immense terminal switching and other expenses; their switch tracks are something like three times as many as those of our American roads. Whether a road is running three trains past a station or one it has to pay one agent, and its expenses are naturally not relatively so large in the first case; that is one reason why their roads show an increased ratio in this respect on general running expenses. The greater the amount of continuous haul the smaller, comparatively, will be this expense. Thus, on the United Railroads of New Jersey it amounts to about 46 per cent., and on the Pennsylvania Road it is about 63 per cent. According to Mr. Dorsey's argument this would indicate that the Pennsylvania was having an immensely large expense for the difference of curvature and grade in their working expenses; the real reason is simply that the United Railroads of New Jersey is a short line which has an immense amount of terminal and other expenses, while the Pennsylvania main line has no terminal ex-

penses to speak of; it receives loaded cars and passes them over its lines, and naturally the running expenses in comparison with a road having a great amount of terminal and station expenses bear a small ratio. It is hardly fair to compare English roads with a line like the Boston and Albany, which has very few, if any, branches, and the New York Central Road, which is more than half main track (the Pennsylvania Railroad has a larger proportion of branches, and its main line is over one-third of its total), as these English roads are composed of irregular spurs branching out all over the country. Our large trunk lines, starting through trains from the West with a large amount of traffic, hauling their cars directly through to the terminus, naturally have their train average higher than on English roads with their short haul and local traffic. Although, when all allowances are made, it still seems clear that American practice is decidedly ahead of English.

Mr. Dorsey said that he had for this reason taken the roads in Massachusetts, which more closely resemble the English roads in length.

Mr. Wellington said that the question was a large one and deserved thorough investigation. Many unfounded claims were made, probably, on both sides. Thus there had recently appeared in the *Engineer*, for the first time, some full statistics upon the question of coal consumption, which shed quite a new light on the large sized claims which were sometimes made of the vastly superior fuel economy of English locomotives. Four of the English roads give their traffic for ten years; the average of those four roads was from 42 to 46, average 43, pounds of coal burned per mile run. In comparison with these figures we have on the Pennsylvania Road, on passenger trains alone, from 43 to 54 pounds per mile, being about 10 per cent higher. It is entirely fair to compare passenger trains here on such a road as the Pennsylvania with the average of both passenger and freight there, because their average weight, even without allowance for the greater speed of passenger trains, would be about the same; and, in fact, on this basis, what difference there was would be slightly in favor of the English locomotives. It was undoubtedly true that American freight engines burned a great deal more coal than the English, but the reason was equally clear, they hauled much more than double the average load per ton mile; the American engine could show far the best record, and while in part it was excusable that the English trains should average less tons, owing to difference in operating conditions, yet in part it was but fair to conclude that it was due to greater efficiency of management, and to better and more durable locomotives. There was no little reason to believe that the combined advantages of the equalized springs and the truck gave the American engines a considerably higher working ratio of adhesion, but that was too large a question to enter into now.

Mr. Robert L. Harris said that for the purpose of adding to the practical information which is being gathered by reason of Mr. Dorsey's

paper on "English and American Railroads Compared" he recently wrote to his friend, Mr. Andrew J. Stevens, General Master Mechanic of the Southern Pacific Company, at Sacramento, California, asking him, on behalf of our Society, as well as for himself, for some facts about their large engines, and the performance of such machines over the heavy grades of the Southern Pacific Railway near Tehachapi Pass, at which place, in October, 1885, he saw the largest locomotive to which his attention had yet been directed, "El Gobernador."

Mr. Stevens has promptly and kindly sent blue-prints of two of their large engines, one the "No. 229," of the class of 19 by 30-inch cylinders, and one the "El Gobernador," whose cylinders are 21 by 36-inch. He has also sent indicator cards taken on these engines while at work; that on the "No. 229" being taken while hauling 496¼ tons (inclusive of engine and tender, 93 tons) up a grade of 105 feet per mile. He has sent a blue-print of the profile of the railway from Los Angeles to Sumner, showing "the grades over which the engines above referred to are running, and upon which the tests below reported were made." The profile shows a division of 168 miles long of heavy grades, much of the distance being on gradients of 116 feet to the mile. "The division is a succession of ten-degree curves."

The two large engines mentioned were built at the Central Pacific Railroad shops at Sacramento, California; the "No. 229" in 1882, and "El Gobernador" in 1883.

The total length of engine and tender, "El Gobernador," is 65 feet 5 inches.

Mr. Stevens states that "these engines are easy on the track, and not expensive to maintain for such large engines performing such heavy service." The following is Mr. Stevens' statement showing the performance of these engines compared with the ordinary 10-wheel 18 by 24-inch cylinder 40-ton locomotive working upon the same division:

"Comparative statement of 18 by 24-inch 10-wheel (6 wheels coupled) 40-ton engine; 19 by 30-inch 12-wheel (8 wheels coupled) 61½-ton engine; and 21 by 36-inch 14-wheel (10 wheels coupled) 77-ton engine, drawing freight over the Los Angeles Division of the Southern Pacific Company between Sumner and Los Angeles:

Number of Engine.	Gross Tons to Train.	Miles to 1 Ton of Coal.	Wages of Engineer and Fireman.	Total Cost.	Cost per Ton per Mile.
18 x 24	220.25	20.77	.0740	.4678	.002124
19 x 30	378.58	16.88	.0814	.5345	.001412
21 x 36	595.33	13.81	.0851	.6351	.001067

"Cost of coal $7 per ton of 2 000 pounds."

"The gross tons hauled by these engines as mentioned in the report were arrived at from special tests for a given period." Mr. Stevens, however, states "that these engines are daily doing the same work as shown in the statement, and are giving excellent satisfaction."

It will be seen that, according to the report, the cost per ton per mile is with the heavy 77-ton engine only one-half of what it is with the 40-ton engine.

Can the above performance be excelled by any road with equally heavy grades and severe alignment?

If not, then the Pacific Coast may lay claim to having built, under Andrew J. Stevens, Master Mechanic, the best performing locomotives for heavy service. According to the memoranda by Arthur Brown, Superintendent of Buildings and Bridges of the Central Pacific Railroad, read at our last meeting, the Pacific Coast has also built the largest railroad ferry transfer boat.

The above data are from the standpoint of the mechanical engineer. It is desirable to have the views of the civil engineer of the road as to the opinion that such heavy engines "are easy on the track," for we might learn that the reduced expense of the engine service may be somewhat canceled by the increased cost of road-bed, bridges, tracks and their maintenance. The "blue prints" mentioned herein are presented to this Society in the name of Andrew J. Stevens, of Sacramento, Cal.

Mr. Robert L. Harris, at a subsequent meeting, said that further information in regard to the large engines mentioned had been received from Mr. A. J. Stevens, as follows.

	Engine No. 229.	Engine No. 237.
Gauge	4 feet 8½ inches.	4 feet 8¼ inches.
Actual weight in working order, exclusive of tender	123 000 pounds.	154 000 pounds.
Actual weight on drivers	106 050 "	130 000 "
Weight of tender (light)	32 000 "	32 000 "
Weight of tender, including fuel and water	63 000 "	63 000 "
Weight of locomotive and tender in working order	189 000 "	217 000 "
Cylinders	19 by 30 inches.	21 by 36 inches.
Driving-wheels, four pair, coupled	55 inches diameter.	
Driving-wheels, five pair, coupled		57 inches diameter.
Total wheel base	53 feet 1¾ inches.	52 feet 7¾ inches.
Driving-wheel base	15 " 9 "	19 " 7 "
Rigid-wheel base	9 " 9 "	14 " 7 "
Boiler, steel, 7/16 inch thick	54 inches diameter.	56 inches diameter.
Height of center line of boiler above rail	6 feet 8 inches.	6 feet 11 inches.
Fire-box	9 feet long by 34 inches wide inside.	10 feet 6 inches long by 34 inches wide inside.
Combustion chamber	52¾ inches long.	50¾ inches long.
Tubes	166, 2¼ inches by 12 feet.	178, 2¼ inches by 12 feet.
Heating surface fire-box	118.8 square feet.	197 square feet.
Heating surface flues	1 076.7 square feet.	1 154 " "
Tank capacity	3 000 gallons.	3 000 gallons.
Steam ports	1⅛ by 14 inches long.	1⅛ by 16 inches long
Exhaust tips (two)	4 inches diameter.	4½ inches diameter.

The above figures are actual dimensions, weights, etc., and may vary slightly from the figures in the blue prints, which were made from estimates while the engines were under construction.

In regard to the last paragraph of the preceding remarks, Mr. W. G. CURTIS, M. Am. Soc. C. E., Superintendent of Track for the Southern Pacific Company, says:

"On a track built especially for such engines, with seventy-six pound rail, large ties closely spaced, good ballast under the ties, and steel rail of best quality, so that the pressure on the smallest possible area of wheel and rail in contact shall not approach the elastic limit of the metal; and, moreover, if water is used as a lubricant between rail and wheel flanges, and will accomplish what is claimed for it, I should say decidedly that the cost of maintaining track under any given amount of traffic hauled by the large engines should not exceed the cost of keeping up the road under ten and twelve wheel engines of the ordinary type."

The rails now in use are fifty-pound steel; the ties are red-wood, not too large nor very close together.

T. C. CLARKE, M. Am. Soc. C. E., said that a comparison of the cost of motive power on the elevated lines of New York with that on the underground lines of London may be interesting, as another example of the correctness of the position taken by Mr. Dorsey.

The statement is taken from the report of the Manhattan Company to the State Engineer for 1884, and the reports of the Metropolitan District lines of London for the same year. The money is given in English currency in both cases.

Receipts of the London underground lines were £1 012 000; expenses, £434 000; leaving net, £578 000. Number of passengers carried, 114 500 000. Cost per passenger $\frac{9}{10}$d.

Receipts of New York elevated lines, £1 345 000; expenses, £777 000; leaving net, £568 000. Number of passengers carried, 97 000 000. Cost per passenger $1\frac{92}{100}$d, or more than double that of the London lines.

Hence most persons have assumed that the London lines were worked more economically than the New York elevated lines, all of which confirms the truth of the wise man's remark: "There is nothing so fallacious as facts—except figures."

The truth is this: The trains of the New York lines, owing to the light traffic on the Second and Ninth Avenues, and to the heavy traffic of morning and evening being in one direction only, have to travel four times as far as the London trains do, owing to their traffic being concentrated all around a circle and inside of it.

The train mileage of the London lines for the year above given was 1 647 000 miles, while that of the New York lines was 6 057 000 miles. The receipts per train mile run on the London lines was 13s.; cost, $5\frac{21}{100}$s.; net, $7\frac{79}{100}$s.

The train mileage on the New York lines was 6 057 000 miles; receipts per train mile, $4\frac{1}{2}$s.; cost, $2\frac{56}{100}$s.; net, $1\frac{94}{100}$s. Hence it appears that while the receipts per train mile of the London lines was nearly three times as much as on the New York lines, the cost per train mile (which is got by dividing the total working expenses by the total train miles run) was less than one-half.

The returns also enable us to state the cost of motive power, only omitting cost of maintenance of roadway and stations, and of general expenses.

The London trains cost 3s. 4d. per mile run; the New York trains 1s. 9d. per mile run.

The economy, not only of motive power, but of all expenses of the New York over the London lines, is due to the use of lighter and better designed rolling stock, at slower speeds; as well as—possibly—to better management.

The London underground trains weigh about 140 tons, carry 300 to 330 passengers, and run 18 miles per hour. The New York elevated trains weigh about 80 tons; carry, seated and standing, an average of 300 passengers, and run 13 miles per hour.

The cost of maintenance of the "flimsy" iron structures upon which these trains run, is much less than that of the "solid road-bed" of the underground lines.

Finally, if the cost of motive power and train service on the New York lines was as great as that on the London lines, the receipts would not be sufficient to pay running expenses.

Walton W. Evans, M. Am. Soc. C. E., said, by letter, quoting from Alexander Von Humboldt, that "the chasms which divide facts from each other are rapidly filling up; and it has often happened that facts observed at a distance have thrown a new and unexpected light on others nearer home, which had long seemed to resist all efforts at explanation."

Mr. Evans, continuing, said that the paper of Mr. Dorsey is one that deals with a subject of vast importance to railway interests. This subject was handled by Dr. Lardner, more than a third of a century ago, with marked ability, in a work entitled "Railway Economy." Then this great moving power was in its infancy, and but hundreds of millions of money invested in it. Now it has absorbed thousands of millions, and become one of the chief factors in the progress of nations throughout the world. Mr. Dorsey has rendered a signal service to the railway interests of any country by comparing the systems of the two countries which were leaders in this great enterprise, and analyzing the results, first, of cost, and then of operating, through which results could be arrived at and reforms instituted when required. Mr. Dorsey took on himself a labor of no small magnitude when he sat down to

write his paper and bring order out of the chaos of interminable rows of figures. To write a sermon, an essay, or an editorial for a morning paper is mere child's play to tackling the figures that make a table of comparison, when those figures amount to millions of units, and when the hundredth or thousandth part of a unit plays an important part in the result sought for. We have Mr. Dorsey's paper before us, and it now remains with us and our friends, the engineers on the other side of the Atlantic, to examine it lynx-eyed as to the methods by which he arrived at his results, and the correctness of his figures; if these are not correct his results fall to the ground, and lose their influence to become factors in working out railway economy. Mr. Dorsey calls on all engineers to examine his figures, and if they can find errors to point them out. A year and a quarter have passed since his paper was read, and, as far as the writer knows, his figures remain unchallenged. In England, the writer has heard that his figures have been met by assertions, and no proof given or offered. Engineers have nothing to do with mere assertions. Leave them to lawyers, whose business it is to befog a jury and make black appear to be white. It has been told to the writer that a member of the Institution of Civil Engineers asserted at the Institution recently that "American locomotives were short lived," and that they were "cheap and nasty" (a questionable expression, but one much used in England). Another member of the Institution, in alluding to American locomotives, said "they did very well on the rough roads of America, but soon wriggled themselves to pieces if put on the good tracks of England." This man was, no doubt, sincere and conscientious. It is astounding to see what people, not lunatics, will believe when they wish to believe it. A ship that can stand up gallantly in a rough sea, in howling storms, is not going to pieces in a smooth sea, when urged along by gentle breezes. The author of the first remark, if properly reported, should recollect that it is a naughty thing for a man living in a glass house to throw stones. He was the engineer and contractor for two narrow gauge railways at Toronto in Canada, and furnished the rolling stock, all built in England. His brain must have had visions of that rolling stock passing before it when he applied the words "cheap and nasty" to American locomotives. In 1874, Mr. Higginbotham, the Engineer-in-Chief of the English Colony at Victoria in Australia, in his report to his government (a parliamentary document) says of this rolling stock (in describing the Nipissing, 88 miles, and the Toronto, Gray and Bruce Railways, 190 miles long): "The two lines to which I have referred were stocked at first with engines, carriages and wagons built in England, which proved complete failures, and have been replaced by American engines and cars; these are found to work well."

"The rigid wheel base of the English rolling stock had been tried and condemned." "The Master Mechanic (Locomotive Superintendent), who is an Englishman, told me that he preferred American to English

engines and rolling stock for railways in Canada." Living in a glass house like this one, that was clearly "cheap and nasty," it does not come with good grace for this gentleman to throw stones at American engines. Before taking Mr. Higginbotham out of Canada, let us revert for a moment to what he says in his report on the Grand Trunk Railway, an English line intended to be a model one, and equal to the best in the world (it ought to be, it cost enough). Mr. Higginbotham says: "English engines and rolling stock were tried but had to be abandoned, and the American type adopted." The writer has a letter of Mr. Ross, the Chief Engineer of that Railway, in which he says (after alluding to his English model engines being altered to American patterns): "On the breaking up of the frost we never could keep the English engines on the track, except at a slow speed which defeated our object."

In reviewing this paper of Mr. Dorsey's, and looking at the tremendous differences he makes in comparing the railways of England with those of America as to economy in operating, it is clearly the locomotive we must look to as the prime factor in working out this problem, and getting at the astounding results put down to the credit of the American system. There is no use in meeting a question of so much importance to the world with sneers or assertions that American railways are "cheap and nasty," or say that their engines are "gingerbread peacocks," that "wriggle themselves to pieces on a good road," and that "they are here to-day and gone to-morrow." Assertions are not arguments, we give facts and figures, and we wish them controverted by facts and figures, or their correctness admitted. The splendid results shown in Mr. Dorsey's paper, when comparing the American with the English system, appear at first sight to be entirely the work of the locomotive. The writer begs to say that a part of these results belong to the American system of cars; long cars resting on two four-wheeled bogies having chilled cast-iron disk wheels, the safest and most economical wheel ever put under a railway car. This has been admitted by eminent English engineers, among them Sir Douglas Fox, Cor. M. Am. Soc. C. E., in his paper on the Pennsylvania Railroad read at the Institution of Civil Engineers. Another point of merit in the American car is the use of oil in the journal-boxes instead of grease. Mr. McConnell, Locomotive Engineer of the London and North Western Railway, tried a set of six American boxes on the tender of a locomotive, and six English boxes at the same time, for four months, and showed that while the American boxes averaged a cost of 1½d. a day, the English boxes cost 9d. a day. See paper read by Mr. Hodge before the Institution of Mechanical Engineers, October 27th, 1852, at Birmingham. Let any one apply this little economy to a rolling stock of 50 000 cars and 2 500 locomotives and see if it does not amount to something in a year. The greatest merit the American car has, when compared with the English, is its being mounted on eight wheels, while the other rests on four

wheels only. In running these latter, the whole car and its load feel every inequality of the road, and oscillate in the direction of its length, and by so doing render null a part of the power of the engine. In the other case the bogies feel the inequalities of the road, but the body and the load do not, and run with great steadiness. In corroboration of this the writer quotes from a report of J. Boyd Thompson, Manager of the Northern Railway of Buenos Ayres, to his Directors in London, dated June 27th, 1867. "Our stock of carriages consists of ten made in England and two in the United States. During the past ten months repairs to English carriages amount to $4 086 currency each, whilst during the same period the American carriages have cost nothing for repairs, and are at present in better condition than those made in England, though they have been in constant use since the line was first opened. I may also remark that their chilled-iron wheels scarcely show any perceptible wear. The American carriages are in every respect better and more comfortable, requiring less than one-half the power to propel them that is necessary for the English." It has been proved that the English carriages are much more injurious to the permanent way and works, and likewise in proportion more injurious to themselves than those of American make. "I most strongly recommend the American model carriages and wagons. They cost less, are not so expensive to keep in repair, run easier, and cause less wear and tear on the permanent way." There, that's pretty liberal coming from a Scotchman. He clearly did not think the American cars "cheap and nasty."

Before leaving the Central Argentine Republic, the writer desires to put on record a line or two about the Central Argentine Railway, built by Messrs. Brassey, Wythes & Wheelwright, of London. They sent to the writer for the whole rolling stock required. The carriages and cars asked for were sent out. The locomotives could not be sent, as the engine works were all engaged by the Government, as we were in the midst of our civil war. Some time after, when this railway was nearly completed, Mr. Wheelwright, in writing from Rosario, said, in a lamenting tone: "You would have saved us a mint of money if you could have sent us American engines." It is clear he did not think American engines "cheap and nasty."

This railway, 243 miles long, was over the pampas, and nearly level and straight for the whole distance.

This superiority of the American railway rolling stock is not a new subject for discussion, as it has been talked about and written about ever since the earliest dawn of the railway era. Its merits were soon talked of in England, and, as early as 1837, Norris & Son, of Philadelphia, were called on to build seventeen locomotives for the Gloucester and Birmingham Railway. They gave satisfaction (it was before the time when American engines were called "cheap and nasty"); other orders followed, but the builders in England grew excited and obtained from the

Lords of the Treasury an order prohibiting the importation of locomotive engines into England. The history of this is to be found in the *United States Magazine* for June, 1855.

In 1849, Mr. F. Passavant, an English engineer, came to the States to study the American engine. On returning he published a series of articles on the American locomotive in the *Glasgow Practical Mechanics' Journal*, Volumes 2 and 3, which are interesting. He appears to have grasped at once all the main points of merit in the American engine, and admits them as freely as any American could do. He compares an English slab-frame and an American bar-frame, and shows that the latter is practically and scientifically the best in proportion of 4 088 to 15 232. He describes the merits of the bogies and the use of outside cylinders, and gives his reasons. He says: "In their frame the Americans have successfully attempted to give steadiness, stability and durability to their engines. The above three virtues are solely dependent on a sound, well constructed frame."

"On most English railways, experience has shown that the resistances on a level are twelve pounds per ton. In the United States the resistances appear to be not more than three pounds per ton." [Extract from Mr. Isaacs' paper on "Locomotive Power," in *American Locomotive Engineer*, December 3d, 1858.]

In 1880, Mr. Higginbotham, Engineer-in-Chief for the Colony of Victoria, Australia, in a letter to the writer says: "The Rogers' engines you sent us have done and are still doing splendid work. They are hardly ever in the shops for repairs, are as easy to ride on as a first-class carriage, and are certainly lighter on the permanent way than any other engine which we have. If they had been built here their merits would have been loudly proclaimed, but as they were not, nothing is said about them, and so profound is our provincialism, that any one who published their merits would almost surely make himself unpopular." In 1877, Mr. Higginbotham sent the writer a full account of all the engines on the Melbourne and Woodend Railway, 97 miles long. This shows that the American engines averaged $2\frac{1}{10}$ pounds less fuel per train-mile than the English engines. They were built for passenger service, but as soon as they got them they were put on goods service. These engines have recently been put in repair and are reported as the best engines in the colony to run the new express from Adelaide to Melbourne. Before Mr. Higginbotham came here in 1874, a son of the first Governor of Victoria, in a letter to the writer from Melbourne, said: "Mr. Higginbotham has started by order of this government to visit the railways of the United States. He has his mind made up against all things American."

In 1854–55, the writer directed the building of a branch of the Copiapo Railway, in Chili, for a London company. It ran to the rich silver mines in the district of Chauar Cillo. It had a summit of 4 467 feet,

the highest then known. It had gradients of 5 per cent., and curves of 500 feet radius. The engines were built in England, had bogies and three pair of driving wheels. In discussing "Steep Inclines and Sharp Curves" at the Institution of Civil Engineers, these engines were referred to as giving great satisfaction on account of their having bogies. Now, the fact is these engines sunk the entire capital of that company in nine years, and they had to sell out to the Copiapo Railway Company.

In a private letter of Mr. P. Gould, the Locomotive Engineer of the Copiapo Company, to Mr. Hudson, Engineer of the Rogers Locomotive Works, he says: "Your two last engines are working successfully on the grades of the Copiapo Extension Railway. There was much talk about the fuel burnt. I was afraid the men might be mistaken about the weight of the coal used, and did not say anything to you about it. Now, however, after three months' experience, we are satisfied that we can haul 50 per cent. more load with 20 per cent. less fuel per mile than the English engines " This is much more than I expected. "The difference between these engines is that the old engines have ruined the English company who owned the line before, they having sunk the entire capital, while our engines are making it a very good business for this company. It is true that we bought the line for a very low price; but even at the price it cost the other company it would have paid a fair interest."

In 1869, Mr. Zerah Colburn, by request, read a paper, No. 1230, before the Institution of Civil Engineers, on "American Rolling Stock." In a letter to the writer he asked for some data on the subject. The writer sent him a good deal, and then told him: "You will not dare to get up in the presence of any body in London and give this as I give it to you, for your bread and butter is, in a measure, mixed up in this matter." Mr. Colburn did not give the data I gave him, but contented himself with saying that the chief differences between American and English rolling stock was a matter of "toilet." In his paper he describes running a test train over the entire line of the Erie Railway to get at the engine power required on each division. In the discussion that took place on this paper Mr. Berkely doubted the correctness of Mr. Colburn's figures, as he thought no engine ever made could give such results.

The *Engineer*, of London, in speaking of engine trials made under the direction of the writer on a government railway in Chili, in 1859, said that such results had never been obtained by any engine, and never would be. In a discussion on the economy of fuel at the Institution of Civil Engineers Mr. Lloyd, in referring to the Chili trials, said that "the English engines showed the greatest economy, as proved by Mr. Evans' experiments." The fact is that these trials proved the reverse, and Mr. Lloyd should have known it, for the locomotive engineer of his road was on the engines all four days of these trials, taking notes, which were like mine.

The Tongoi Railway, on the coast of Chili, has in it, on the summit division, gradients of 1 in 20. This road was originally stocked with engines and cars from England. It is owned chiefly by Englishmen. In 1870, Mr. Green, the Manager, sent to the writer for some American engines to work his steep inclines. After these engines were sent out he was asked to give some relative data in reference to the performance of these engines with the English engines. He wrote, "I cannot give you what you ask for, as I am now doing all the work on the summit division with the Campanil, one of your engines, where I formerly occupied the services of two."

Mr. J. C. Hoadley, a mechanical expert of high standing, was sent to England in the midst of our civil war, to procure guns for the defense of Boston harbor. He was delighted with all he saw, Scott Russell and others having been very kind to him, showing him the railway works. He said to them, "Gentlemen, this is all very magnificent, but it is also very extravagant. We cannot afford such expenditures as I see here on all sides. If by some great convulsion of nature we in America were to lose all our rolling stock, and you, in the generosity of your dispositions and kindness of heart, were to offer to replace it as a gift, we could not afford to accept it."

In the centennial year, Mr. Massey Bromley, of the Great Eastern Railway, was sent here to study American locomotives. The writer gave him letters of introduction. After spending three months in the study he came for, he came to the writer's office and said, "I am delighted with all I have seen, and am going home to build American locomotives." The writer said, "Will you build American driving wheels?" He said, "Yes, as I find them better and cheaper." Being asked if he intended to build American frames, he said, "No; your frames are too expensive, we cannot afford them." The writer replied, "You will not have an American locomotive, for the frame is the backbone, one of the chief points of merit on the whole machine."

In 1877, the writer sent two patterns of engines, by order of the government of New Zealand, to their Locomotive Engineer, who was in charge of the motive power of more than one thousand miles of railway. He, during two years, in many letters, spoke in the highest praise of the merits of these engines, saying, "They are doing wonderful work; day after day they are turned out to run the express at thirty miles per hour on forty-pound metals, and never a hitch takes place. They keep time and work cheaply, and the men who drive them all maintain that they are the best engines they have ever been on. We are running the American engines imported for the Rakia and Ashburton Railway, and find them the most steady and smoothest-running engines in the country. I have much pleasure in informing you that the Baldwin engines are doing first-class work. About ten days ago, one of these hauled the heaviest train ever moved by one engine in this colony. It

consisted of one hundred and eight wagons, loaded, and was estimated to weigh one thousand tons. The train was within one hundred feet of half a mile in length; speed, twelve to fifteen miles per hour; coal, native lignite. These engines are making a name for themselves. I should not be surprised to see American engines entirely adopted in this country. The Rogers passenger engines work splendidly. They are making each forty thousand miles per year. The more I see of American engines the more I like them. In the long run, the American engines will prove their worth to the most prejudiced mind. I used them on all the bad roads. They run over roads that would destroy our heavy English engines in three months."

The standard gauge of New Zealand is 3 feet 6 inches.

Mr. James Hall, an English engineer of great ability and standing, director and manager of the motive power of all the government railways of Chili, has been ordering American locomotives for about twenty-five years. In writing for more engines, in 1882, he says: "You will notice that I recommend more powerful engines than the old 14-inch cylinders. On this section we have long grades, and a heavy traffic always up. Our passenger trains consist of twelve American coaches (equal to twenty-four English coaches). It is only just to the old engines of the class Tano, cylinders, 14 by 24, wheels, 63 inches, to say they have done their work admirably, and are as good and as economical as you will find in any part of the world. The Tano ran nearly one hundred thousand miles without requiring any repairs worth mentioning."

Mr. J. L. Stothart, a well-knnown English engineer, who has been connected with railroad building in England, and who is a member of the Institution of Civil Engineers, came to this country in 1883 to see our railways and the machinery used in working them. On his way home he wrote a letter to Mr. Robert E. Pettit, M. Am. Soc. C. E., Manager of the New Jersey Division of the Pennsylvania Railway, thanking him for permission to ride on the engine, in which he says:

"*Freedom from Oscillation.*—In this respect, and the principal one, I wished to satisfy myself upon, your engines leave nothing to be desired. They are absolutely steady at the highest speed, and upon carefully gauging the framing with the rail, I could never detect any oscillation on a straight track, whatever speed was obtained. On the journey from Trenton to Jersey City on No. 260, we ran three consecutive miles in 58 seconds each, and two miles in 1 minute 58 seconds. There was no swing on the engine at this speed, and I do not think any English locomotive at these speeds would have been so free from oscillation.

"*General Working Arrangement.*—In this respect your engines are perfect. All the handles are brought to one focus, and the introduction of steam reversing gear demands no manual exertion on the part of the drivers. The engines run nearly as comfortably as your carriages."

In the London *Engineer*, of October 1st, 1858, the editor says: "Mr.

Robert Stephenson stated, while in America, that the engines in that country were better than those of English build, while the same gentleman, to the knowledge of the writer, has reiterated the same opinion within the last ten days."

In September of last year, Mr. D. Banderali, engineer of the motive power of the Northern Railway of France, came here to study the American locomotive, and in May, in a French review on railways, gives an account of some of his observations. He says he "was struck by the fact that the number of locomotives was small in proportion to the mileage of the road and the train mileage, and also by the fact that so small a portion of the engines were undergoing repairs in the shops; also by the smallness of the stocks of materials used for repairs. The repairs of the locomotive are reduced by the solidity and simplicity of their construction. One remarkable fact prevails everywhere, and whatever the system adopted, I have found the engines in a perfect state of repair, and the motive power service as satisfactory as possible.

"It is not without difficulty that the American engineers have succeeded in modifying established customs. Their personal intervention, energetic, patient, persistent, at the same time adroit, action, has overcome all opposition." Longer quotations from this paper might well be given, it is all very interesting.

In 1883, the Minister of New Zealand ordered twenty locomotives in England, sending drawings and specifications. At the end of eighteen months he heard of two being finished and ready to ship. The Agent-General informed him that as these engines weighed each ten tons more than the contract called for, he had better strengthen all his bridges, or they would break them down. Wishing engines badly, he ordered twelve of the Baldwin Locomotive Works in Philadelphia. They were all completed and shipped in three and one-half months. The Minister then said in his report to Parliament: "The best of this business is that these engines will cost, delivered here, £400 each less than the English engines."

In 1852, Mr. Edward Woods, a distinguished engineer of England, at present President of the Institution of Civil Engineers, was called by the London and North Western Railway Company to examine and report on the causes for the very excessive amount of fuel consumed on the Southern Division over that used on the Northern Division. After great labor during more than a year, and after equating the cost of everything that could be equated, they found a large amount unaccounted for, except by the use of large inside-connected engines on the Southern Division over the amount burned by the smaller outside-connected engines of the Northern Division.

Mr. Woods did not find that it was the largest amount of fire surfaces in an engine that always produced the largest amount of steam, nor did he find anything to prove the inferiority of the outside-connected en-

gines of the Northern Division on a single point, nor did he find that inside-connected engines were always steady running engines.

In a recent letter to Mr. Woods, the writer mentioned having read Mr. Stroudley's paper on his new design for engines, and said it looked to him as if they were going backwards in engine construction in England; and he thinks from the remarks made by W. H. Mills, of the Great Northern of Ireland, in the discussion, that he supports him in his views. To build engines with crank-axles makes the center of gravity exceptionally high, and then to place the driving wheels as leading wheels, and claim these points as merits in engine construction, is to American engineers incomprehensible.

The London *Railway News*, of November 16th and 30th, and December 7th, 1872, and February 22d, 1873, published some very interesting statistics of comparisons between four English and four American railways. They are too long to go into a paper of this kind. One of these comparisons may be mentioned. After stating that the business of the New York Central Railway was greater than that of the London and North Western Railway, it shows that the former is worked by $\frac{50}{100}$ of a locomotive per mile of road, while the latter occupies the services of $1\frac{11}{100}$ engines per mile of road.

The writer has now mentioned the opinions and writings of many clever engineers, most of them Englishmen, and has probably given a hundred times more than is necessary to convince any unprejudiced mind that there is not only merit, but great and wonderful merit in the American engine. But if their writing had extended to a thousand times as much, it could not have convinced any one of those who are blinded by prejudice and who are skeptics as to anything good having originated in America. The writer is inclined to think that if that great man, George Stephenson, that great master of mechanical instinct, should come up from the tomb to see the railways and judge of the progress that had been made, by the money results, and comparisons in different countries, particularly those of England and America, he would shrink back in holy horror.

It is generally believed that a first-class railway in all its appointments, should be able to carry vast amounts with regularity and speed, without accident and without straining any of its parts. Let us glance at a few things that have been done in America, and see if they have ever been matched in any other country.

In the Centennial year a train was run from New York to San Francisco, a distance of 3 317 miles, in 83 hours and 27 minutes actual time. This is nearly forty miles per hour for the whole distance. This train passed over four mountain ranges, one with a summit of 5 100 feet. On the Pennsylvania Railroad Division this train was run at a speed of 43½ miles an hour crossing the Allegheny Mountains, total distance being 439½ miles, and without making a stop. Mr. Howard Fry, an

English mechanical engineer, Locomotive Superintendent of the Philadelphia and Erie Railroad, October 27th, 1877, ran a train of 100 eight-wheel cars loaded with coal oil and grain, weighing 2 201 tons (2 240 pound tons); length of train, 3 127 feet; speed of train, 10¼ miles per hour; engine No. 41, cylinders 20 inches by 24 inches; weight on drivers, 88 000 pounds; road approximately level. This engine ran 26 trains in this month, with from ninety to one hundred and six cars in each train.

The Reading Railroad of Pennyslvania, which transports much the largest tonnage of any railway in the world, in 1885 carried as follows:

Passengers carried.....	23 531 057
Coal carried in 2 240 pound tons.....	12 530 594 tons.
Merchandise carried in 2 240 pound tons.....	7 493 510 "

The coal trains in summer are made up of 125 cars, and in the winter 115; average coal carried per train, 800 tons. A train on a branch of this road to New York, May 9th, 1884, ran 10 consecutive miles at an average of 75 miles per hour; work of this kind could not well be done by railway machinery that was "cheap and nasty."

On August 18th, 1886, a special newspaper train, No. 11, was run on the New York Central Railroad from Syracuse to Buffalo, $148\frac{7}{10}$ miles, at average speed of $65\frac{6}{10}$ miles an hour. On one section of ten miles the speed was 75 miles per hour. This engine had made her regular trip of 300 miles the day before, and did the same the day after.

Mr. Dorsey, in closing the discussion, said that Mr. C. E. Goad was very much mistaken in saying that the English passenger cars, by means of their side doors, can be unloaded and loaded in one-third the time that the American cars can through the two end doors.

Mr. Dorsey had personally taken the time of 531 stoppages on trains running into and in London, and 342 stoppages on trains on the four elevated railroads in New York. In all cases all stoppages that were prolonged by block signals, loading baggage or other causes, not caused by loading or unloading passengers, were rejected. The average of the 531 London stoppages was thirty-three and one-third seconds, the average of the 342 New York stoppages was eleven and two-thirds seconds—nearly one-third.

On the London roads the shortest average stoppages were made on the Metropolitan Railway. Theoretically, eight or ten persons should be able to leave or enter a car by one door quicker than fifty persons can by two doors; practically it is not so, as much time is lost by the passengers in finding among the six kinds of carriages on the London trains, the particular kind he or she wishes to ride in. After this is found, much more time is lost in opening doors and looking for a seat, whilst in the American cars there is only one class or kind, the passengers can enter by any door and find seats after the train is in motion.

He considered that Mr. Goad's remarks about lavatory conveniences on the cars used in the United Kingdom were very misleading. It is true some very few of the first-class carriages have water-closets. The Board of Trade Reports for 1884 show that only five per cent. of the whole travel of the United Kingdom was first-class. It is safe to say that not one per cent. of the first-class carriages used there have these conveniences, thus giving this great comfort to only about one person in every two thousand. This is very hard on the majority of travelers, who have no other fault, except being poorer than the few richer or more privileged ones, nature giving to all alike the same necessities and requirements.

Mr. Dorsey fully agreed with Messrs. Collingwood and Shinn that all crossings in populous sections should be either above or below the level of track, whether at stations or any other place. In his paper he advised that laws should be passed compelling this to be done. He would advocate passing laws obliging all crossings, whether for vehicles, animals or foot passengers, to be either above or below grade in all counties or townships where the population averages over forty persons to the square mile.

Few persons have traveled more in the United States and England than himself, and after all this experience he is a firm believer in our check system for baggage.

Recently the London and North Western Railway made arrangements to check baggage from England to New York. Last month he had his baggage checked from his apartments in London to New York by this system, with very satisfactory results, as it enabled him to stop over between London and Liverpool without being troubled to look after his baggage, which he found all right on the New York dock. The railway company gave a slip of paper instead of our brass check. A receipt was given for the baggage when delivered in New York.

In regard to Mr. Goad's experience with his baggage, the remedy is very simple. If he or any one else prefers the English system, they can easily follow it here. There is no law obliging them to patronize the baggage expresses or transfer companies, all are at liberty to follow the English system if they prefer it, and take their baggage in a carriage to and from our railroad stations.

Heretofore all the discussion on the check system has been from the travelers' standpoint, as effecting his comfort and convenience. In the opinion of the author, the English railroad companies are more directly interested in this than the passenger, as by adopting it they could decrease their station expenses largely. He had many times counted over forty porters engaged in loading the baggage at one time, while at the same time many others were occupied on other platforms, especially in unloading the baggage from arriving trains. There must be in some of the large stations in England several hundred porters thus employed.

Over eighty per cent. of these could be dispensed with by adopting our baggage check system, as most of the work they perform is done in the United States by the baggage express companies without cost to the railroads. It is true the porter's pay is very small, about 18 shillings ($4.37) per week, but in the aggregate it must be quite a respectable sum, and of sufficient importance to save.

In reply to Messrs. J. F. Crowell, M. N. Forney, A. M. Wellington, and W. H. White, Mr. Dorsey stated that it is absurd to compare the cost of train miles in the two countries, owing to the American train averaging so much heavier loads than the English. For example, on the Pennsylvania Railroad Division the average load is three times larger than it is on the London and North Western. In comparing the cost per train mile the average load must be considered, or the comparison is false and misleading.

Mr. Dorsey again repeated that the English railroads make no return of the ton or passenger mileage, nor do they separate the cost of freight or passenger traffic.

He had made a great many inquiries in different places; the prevailing rates over different roads were ascertained; and then, by taking the percentage of each class of passenger and freight, the rates, as stated on pages 16 and 735 of his paper were adopted.

Since they were first published and discussed, eighteen months had elapsed without their being disputed in any way; but, on the contrary, they have been confirmed from many reliable sources. For example:

The *Engineering*, of London, of August 20th, 1886, page 187, in speaking of "British Railway Administration," says:

"The average receipts from goods traffic in 1885 were only about 2s. 9d. per ton, and if we reckon that the average ton-mile rate was only 1d.—although it is certainly something more—the average length of lead for goods traffic would come out as thirty-three miles. * * * The train-mile receipt is not a function of the rates and fares so much as of the weight of the train, or rather of the live load carried, and if the English railways will persist in carrying loads of 50 to 100 tons, where they might just as easily carry three or four times that load with very little increase in the main items of working cost, they must expect not only a low range of train-mile receipts, but a low range of dividends as well. * * * And each passenger travels a distance of six miles."

This latter worked out, makes the average passenger fare per mile somewhat greater than the author's estimate, showing that he is conservative in his figures.

The preceding is an unequivocal indorsement of the author's estimated average freight and passenger rates, and also of the estimated train load based upon his rates. It also confirms the views of the speaker as expressed in his different papers, that the English train load

in freight and passengers is too small for economical working, and by making the loads much larger the rates could be lowered, or the dividends increased.

Mr. J. S. Jeans, the able statistician of England, says, on page 181 of his "Annual Statistical Report" to the British Iron Trade Association for 1884:

"The average ratio quoted for the transport of iron ore and coal in England could be varied either upward or downward according to the distance or lead. But if the average rate is taken at 1d. per ton per mile, which is probably as near the mark as we can get, instead of 1.02d. as shown is the average of iron ore."

If the average freight charge per ton per mile on iron ore is 1.02d., and on iron ore and coal 1d., the author's estimate of 1d. average charge per ton per mile on all freight is much too low. If it is too low, the estimated train loads in England are too large, and should be reduced.

Sir B. Samuelson, M.P., in his pamphlet, "Railway Goods Tariffs," 1886, gives a long list of freight charges on many different articles between many different points. These charges have been ably analyzed by Mr. E. P. North, M. Am. Soc. C. E., in his discussion on this paper. See page 766 of this volume. These rates more than confirm the author's estimates.

In the evidence of Mr. Alexander Meadows Rendel, C.E., in the "Report of East India Public Works," printed by order of the English House of Commons, on page 502 he says:

"Assume, also, that the average charge in Great Britain and Ireland for carrying a passenger 1 mile is $1\frac{1}{16}$d., and for carrying a ton of goods (including minerals amongst goods) $1\frac{1}{8}$d. per mile. I am obliged to assume these figures, because no English company either publishes its average charges, or states its charges in such a way as to allow the averages to be ascertained. The object here is to assume averages favorable to the English lines; that is to say, rather below than above the fact. And I am quite satisfied that in taking $1\frac{1}{16}$d. for passengers and $1\frac{1}{8}$d. for goods I have done so."

These last are the identical figures arrived at and used in the paper under discussion, as will be seen at page 16.

Mr. Dorsey had seen letters from some of the principal railroad managers of England in reference to his paper, but none denying the correctness of his ton or passenger mileage estimate.

In answer to all remarks about the cost of "repairs and renewals of locomotives," cost of "motive power," "maintenance of way," and "total cost of operating expenses," he referred to his Table No. 45, where thirteen of the principal railroads of the United Kingdom are compared with fifteen representative roads of the United States, all this data being from official sources, except the passenger and ton mileage.

Backed by this strong corroborating evidence, he felt that he could very properly repeat from his first paper: "He hopes that the railroads which are so largely interested in this question, will promptly replace his estimates of ton and passenger mileage by their official figures. Until this is done he claims that these figures should be accepted as correct."

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TRANSACTIONS.

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(Vol. XV.—November, 1886.)

THE AMERICAN LINE FROM VERA CRUZ TO THE CITY OF MEXICO, VIA JALAPA, WITH NOTES ON THE BEST METHODS OF SURMOUNTING HIGH ELEVATIONS BY RAIL.

BY A. M. WELLINGTON, M. AM. SOC. C. E.

READ AT THE ANNUAL CONVENTION, JULY 3D, 1886.

WITH DISCUSSION.

The line described in this paper, and illustrated in the accompanying maps and profiles, is one located by the writer, as consulting and afterward chief engineer, from the Port of Vera Cruz to the City of Mexico, via the City of Jalapa, being a parallel line to the existing Mexican Railway—the first railway built in Mexico—in the sense of connecting the same termini, although following a very different route and of a very different character.

All the features of interest and of difficulty, both in the line here

described and in the line of the Mexican Railway, are confined to the mountain grade by which the necessary abrupt ascent from the level of the sea to the level of the plateau, 8 000 feet above the sea, is accomplished. Once on the plateau there is no great difficulty in going almost anywhere with very light work; many high mountains being scattered around, even on the plateau, but disconnected, with flat lands between.

The elements which appear to make the mountain grade of this line particularly worthy of description are these:

First.—It is believed to be by far the longest continuous grade line ever located; 116.9 kilometers (72.64 miles), having been located on an unbroken 2 per cent. grade (105.6 feet per mile), rising in that distance from elevation 600.4 feet (183 meters) to elevation 7 923.3 feet above the sea (2 415 meters). The accompanying Plate LXXXII shows graphically the extent of the contrast in this respect with some of the other great inclines of the world.

Secondly.—It is believed to be on the lowest rate of grade, by about 2 per cent., ever successfully attempted for accomplishing within a limited distance, either by a continuous grade line or otherwise, a rise of over one-half as much as was attained on this line. The grounds for this belief also are shown in the accompanying Plate LXXXII.

Thirdly.—The line is believed to be, by probably one-half at least, the cheapest line per mile which has ever been actually located, with equally favorable alignment, for attaining within a limited distance as much as one-half the rise actually attained by this line, either by continuous or broken grade lines, on any rate of grade. As for this, Table No. 1, Plates LXXXIV and LXXXV and the general knowledge of engineers is the only evidence that can conveniently be appealed to, or which it is worth while to attempt to present.

Finally.—It appeared that the manner in which the line was obtained might have a certain instruction and encouragement to those who may be dismayed, as was the writer, by having similar problems of unusual difficulty suddenly thrust upon them, and it was also desired to give, in connection with the description of the line, certain conclusions which the observation and experience of the writer has indicated—not only on this incline, but on eight or ten others of considerable rise, which have been located or relocated in part or whole under his supervision, aggregating over 24 000 vertical feet—in regard to the most ad-

vantageous and economical manner of dealing with great inclines, under which may be classed anything exceeding 1 200 to 1 500 feet of vertical rise.

It is one of the unfortunate features of the department of engineering to which this paper refers—that of laying out railway lines to the best economic advantage—that a mere description of a located line has ordinarily little technical interest or instruction, since it is ordinarily impossible to so carefully describe any line on paper as to enable even an intelligent impression to be formed as to the real character of the work. If the grades and work be light, it may be because the line was well laid out, or it may be simply because there were no serious natural obstacles in the way. On the other hand, if the grades and work be heavy, it may be due to bad engineering, and so discreditable; or it may be due to the existence of gigantic difficulties, and so an evidence of skill. It is but natural, however, that the magnitude of the natural difficulties to be overcome should in general be regarded as bearing some nearly constant ratio to the magnitude of the works constructed to overcome them; and hence, that, even when the construction of a very costly line may have been, as a matter of fact, an avoidable extravagance, due to lack of skill or foresight, the very magnitude of the works gives more instead of less reputation to the line as an engineering work.

Only in the comparatively rare cases when two independent alternate lines exist between the same termini, is it possible for the engineer to find in printed descriptions of located lines, however perfectly mapped, any rational basis for intelligent judgment. The present happens to be one of the cases in which this is possible, owing to the existence of the parallel line before mentioned, but in order to avail of it, it becomes necessary to enter somewhat into what would otherwise be an invidious —because unnecessary—comparison with the parallel and previously constructed line. The writer feels the less embarrassed in doing this, as, owing to the checkered history of the line, no one engineer can be held responsible for its character, and there were certain circumstances tending to impede entire freedom of choice and proper investigation.

The whole interior of Mexico is a vast plateau, at an elevation of 5 000 to 9 000 feet above the sea, bounded by an abrupt escarpment from which the descent to sea level is almost immediate. The edge of the

plateau is higher and sharper on the Atlantic than on the Pacific Coast, and at no point on either the Atlantic or Gulf Coast is it higher or sharper than directly in line between the capital of the country, Mexico, and its chief port, Vera Cruz. Here two stupendous natural obstacles, the Pico of Orizaba on the south (17 873 feet high), and the Cofre, or "Box," of Perote (12 500 feet high), both of them described in physical geographies as volcanoes, although both are temporarily extinct, and the two connected by a ridge over 10 000 feet high at its lowest saddle —combine to forbid a direct line inward.

Orizaba is one of the three mountains in Mexico covered with perpetual snow, the other two being Popocatepetl (17 884 feet), and Ixtaccihautl (15 705 feet), overlooking the valley of Mexico. These, however, start from a plain 8 000 feet high, whereas Orizaba starts practically from sea level on the coast side, making it in that sense by much the highest mountain on the North American Continent,* and among the highest in the world. Its snow-clad peak is visible 60 miles out at sea, long before there is any other evidence of land, and with the morning sun shining on it is a very striking sight. Its last violent eruption was in 1546, soon after the Spanish conquest, although it now occasionally throws out smoke. Only one or two men have ever ascended to its crater, the first one having been Lieutenant Reynolds, U. S. A., in 1848. The line of the Mexican Railway passes to the south of this mountain as shown on Plate LXXXIII.

The Cofre, or "Box," of Perote (so named from a cylindrical basaltic needle about 300 feet in diameter and 300 feet high which caps the mountain, like a box laid on its peak), although formerly one of the most active volcanoes in the world, and classed as still active, is perhaps permanently extinct, its last, and probably also its greatest, eruption having been to form what looks to be, and is in fact, a frozen river of lava, shown on Plate LXXXIV, extending to and running into the sea 50 miles distant, filling up an enormous barranca or deep gulch in the process, in a manner which was very convenient for subsequently carrying the line over it, as may be seen on Plate LXXXIV. The natural variations in the width of this gulch have caused lakes and frozen "water-falls" of lava, which makes it difficult to believe, as one looks up the slope upon

* Mount St. Elias, in Alaska, is a possible exception, being only about 30 miles inland and its height variously given as 14 970, 16 900, 17 850, "over 18 000" (U. S. Census Report) and 19 500.

it from some commanding point, that the mass is not still flowing, making it a unique and impressive bit of natural scenery. Vessels have been frequently wrecked in the toe of this flow where it enters the sea. It has still hardly any deposit of sand, soil or vegetation on it, that and other facts evidencing that the flow is geologically very recent, not antedating much the historic era.

Around the north side of this mountain, and directly over this lava flow, the line here described passes, as shown on Plates LXXXIII and LXXXIV, being about sixty miles north of the Mexican Railway line at its greatest divergence, the two beginning to come together again very soon thereafter. The summit of Perote is just below the limit of vegetation and of perpetual snow, and it is very easily ascended on horseback to the foot of the "cofre," or box, that fact alone being an evidence to the engineer of how different the topography of its slopes must be from those of its southerly companion. Evidences abound of tremendous flows of lava in remote geologic times, which are now covered to a considerable depth with soil, and in the kind of pocket formed between the foot-hills of the two great mountains, in which lie Jalapa and Coatepec, the detritus of ages has accumulated, including probably great amounts of volcanic ash, so that no rock exists over large areas, as was afterwards discovered, except in isolated points.

Cortez followed this route on his first invasion, as did General Scott 328 years later, but from an early date after the conquest of Cortez, two leading routes have existed between the interior and Vera Cruz, following substantially the two railway lines here described, one through Jalapa, rounding Perote to the north, and the other via Orizaba, rounding the mountain of that name to the south. The northerly line was first constructed, and over it, for 300 years (between 1521 and 1812–20) passed vast sums of silver and gold, practically the entire product of the Mexican mines, amounting in the aggregate to $3 000 000 000, or nearly half of the value of silver in the whole world, which, in 1876, was estimated at $7 232 071 674, exclusive of what existed before 1520, which was relatively little. During all this time the southerly route was an insignificant trail, but early in this century the southerly route took prominence, and the Jalapa *camino real*, or "King's highway" (as the leading roads are still called in republican Mexico), was suffered to fall into decay. It had originally been paved, guttered and curbed for the entire distance from Jalapa to Vera Cruz, some 73 miles, and from Jalapa up the mount-

ain a fine macadamized road, likewise curbed and guttered, existed, and still exists in fine order, having been recently repaired.*

Within fifteen or twenty years after the abandonment of the northerly highway, as early as 1837, the movement for a railway between Vera Cruz and Mexico was begun by Don Francisco Arrillaga, and very naturally, but very unfortunately, the route which had by that time become the only one generally known, assumed a prominence which it held to the end. The very facts which made it best suited for a highway, that a very comfortable valley ran directly up into the bowels of the mountains, from which the ascent was abrupt and sharp to the plains above, made it unsuited for a railway line, but this could hardly be appreciated at that early day.

By 1854, the construction of a tramway from Vera Cruz had been begun, Don Antonio Escandon, a wealthy Mexican banker, who was chiefly instrumental in pushing the project through to completion, having then taken hold of the enterprise. Don Antonio had a large estate near Orizaba, and his property interests may well have somewhat influenced the final decison. However this may be, in 1857, Colonel Andrew H. Talcott, an American engineer, arrived with a staff of assistants, the only member of which now living, the writer believes, is Mr. S. Wimmer, M. Am. Soc. C. E., then a very young man, after whom one of the leading bridges of the line was subsequently named. According to one of the published histories of the road, all these engineers confined their labors to the Orizaba line, that via Jalapa being entrusted to a Mexican engineer, Don Pascual Almazon. According to other accounts, a commission of engineers examined both lines. If the first was the case, it is less surprising that "on comparing the separate surveys," as the history of the road states, that by Orizaba was finally adopted, on the grounds, first, that there was more traffic to be secured on it (which is rather more than doubtful, although the local traffic at best is an insignificant element), and secondly, that "notwithstanding it requires great and costly works, the line presents greater facilities than that by Jalapa, *where the larger number of ravines and the harder nature of the soil would have required much heavier outlay.*" A greater mistake than is contained in the italicized part of the quotation could not well be.

* On the lower part of this highway a splendid stone bridge, the *Puente Real*, or as now described, the *Puente Nacional*, which has been not unreasonably claimed to be "worthy of the best days of Rome," still exists in perfect order, and as showing the fine quality of the Mexican lime, the joints are considerably harder than the stone itself (which is durable, but rather soft), and are worn less.

Colonel Talcott's estimate of the line was $15 000 000, but nothing more was done than to build about ten miles of surface line out of Vera Cruz, until August, 1864, when the military necessities of the Emperor Maximilian led to a real beginning and prompt pushing of the work under English engineers, and by an English company, which still controls it. Beyond a statement that the resumption was "after rectifying the plans of Colonel Talcott," the official history contains no record of the second examination of the whole question of route, which was in fact made, although how thoroughly the writer cannot state.

By 1867 the line was opened from Vera Cruz to Paso del Macho, 47½ miles, and from Mexico to Apizaco, 86½ miles, the rails for the latter being hauled by wagons an average of 200 miles inland, at enormous cost, a hard condition imposed by the Mexican government. A third change of engineers took place about this time, while the heavier parts of the work was still unexecuted. In 1868, the Puebla branch, 29 miles, was opened, the rails for it having been hauled in the same manner. In 1870 the line was opened to Atoyac, 54 miles from Vera Cruz; in 1871 to Fortin; in 1872 to Orizaba, and on the last day of that year the entire line was opened with great ceremony.

Shortly thereafter, in 1884, Don Ramon Zangronez, of Vera Cruz, succeeded in getting a branch line to Jalapa well under way, and in having it assumed by the Mexican Railway, which completed it, as shown on Plate LXXXIII, in May, 1875. It is operated solely by animal power, being probably by far the longest horse railway in the world. Its grades are very severe (10 per cent.), and its curves of ordinary horse-car radii. It is laid for a great part of its length along the old *camino real*, and exhibits the same trait as the main line of the Mexican Railway to the foot of the mountains, that is it runs obliquely across the drainage lines, thus materially increasing the difficulties of both lines, but making the Jalapa line absolutely impracticable for an ordinary railway, even with gigantic work. It was probably some such erroneous treatment of the lower part of the descent which led to the condemnation of the route, as it seems impossible that an ascent from Jalapa on a 4 per cent. grade could have been deemed as serious as that from Orizaba on the adopted line.

The main line thus constructed is still one of the most massive and costly in the world. Its cost was abnormally increased by two causes: First, the political condition of the country, which was so much disturbed

that it no doubt added much to the cost; and secondly, the absurd requirement that construction, including track-laying, should begin from both ends at once, necessitating the enormous expense referred to for hauling rails over execrable roads from Vera Cruz to Mexico and Puebla. In all some 15 000 tons of rails were thus hauled, at a cost, the writer believes, of some $80 per ton, amounting to some $1 200 000 in all. On the other hand, there was little direct inflation of the capital account, most of the share capital representing actual money paid in. The gross nominal cost of the line was as nearly as may be, $40 000 000. Reducing this by one-half, we shall make an ample allowance for the effect of all abnormal causes tending to increase cost of line, and for the cost of the Jalapa horse railway and the small amount of rolling stock (65 engines, 810 cars), leaving $20 000 000 to represent the actual cost of 264 miles of main line and 29 miles of branch. Of this the section between Paso del Macho and Boca del Monte alone, some 60 miles, is in any sense difficult or costly work. The remaining 223 miles is light work, with 1½ per cent. grades, which latter are quite unnecessarily high.

On this basis we may distribute the actual cost (taken at half the nominal) about as follows:

223 miles light work, at $40 000 per mile.....	$8 920 000
60 miles very heavy work, at $184 667 per mile....	11 080 000
283 miles in all, at $70 670 per mile.....	$20 000 000

Both the grades and curves on this line are very severe. Only 10 miles out of Verz Cruz 1.5 per cent. grades begin, which shortly thereafter are increased to 2 per cent., 2.5, 3, and at last to 4 per cent., which latter is entirely unbroken for the last 13 miles of rise, and used also at several other points on the ascent. Curves as sharp as 325 to 350 feet radius (16 degrees 30 minutes and 17 degrees 40 minutes) are used, and six or eight reversed curves of these radii often succeeding each other without any tangent between them, and without any grade compensation, making the virtual gradient fully 6 per cent. Fairlie engines are used to operate this grade between the summit at Boca del Monte (107 miles from Vera Cruz) and Cordova. The remaining 157 miles to the City of Mexico, as well as the lower and easier part of the mountain grade (which, however, has 2½ to 3 per cent. grades, increased by unreduced curvature), is operated by American engines. Very naturally both the freight rates and the expenses are fabulously high,

receipts ranging from 10 to 12 cents per ton mile, and as high as $8 per train mile; expenses being from 50 to 60 per cent. of receipts. To show how radically the cost and revenue from the operation of this line differs from anything with which we are familiar, it was calculated in 1883 that with the Mexican rates the New York Central would earn $27.25 and the Erie $28.50 per freight train mile, and their total freight earnings would have been in one year $297 025 000 and $244 300 000 respectively—$168 000 000 more than the Central's whole capital account, and $93 000 000 more than the Erie's.*

There are fourteen tunnels in all on the line, none of them, however, very long, and about as many viaducts. The grading is, for miles together, almost wholly rock, and the work, as a whole, can only be described as Titanic, so that it is small matter of surprise that almost every one who writes about the line describes it in much the same terms as does Mr. George William Curtis in a late number of *Harper's Magazine* (February, 1886), who chances to be the last writer whose remarks in respect to it have come to the writer's knowledge.

"If it is magnificent scenery that you seek, here at hand, with no intervening ocean, is the railway from Vera Cruz, 260 miles, to the City of Mexico—a marvelous feat of scientific skill, crossing the mountains at a height of 8 500 feet, and bearing you through every climate, amid unimaginable luxuriance and brilliancy of vegetation, changing into temperate hues of hardier growths, with awful mountain abysses between and snow-clad peaks beyond against the deep blue sky."

The line located by the writer rises to almost precisely the same height of summit as the Mexican Railway, and is as nearly as may be of the same length, but in almost every other detail stands in broad contrast with it, thus:

Grade.—Continuous 2 per cent. (uncompensated) against a broken 4 per cent. (uncompensated); including the effect of curvature or of compensation therefor, 2.6 per cent. against 6 per cent.

Curves.—Curves of 289 feet radius (19 degrees 50 minutes) connected by minimum tangents of 40 meters (131 feet), against 16 degrees 30 minutes to 17 degrees 40 minute-curves (325 to 350 feet radius) connected by no tangents at all for many successive reversions. The writer considers that the difficulty and expense of maintaining these

* *Railroad Gazette*, June 8th, 1883.

two limits is about equal, but that the latter is decidedly the most objectionable.

Amount of Curvature.—On Mexican Railway 143 curves on the last 20.14 kilometers of the ascent, against 82 curves on the upper 19 kilometers of the Jalapa line, shown on Plates LXXXIV and LXXXV. The lower portions of the line will be seen on Plate LXXXIV to have much more favorable alignment.

The number of curves indicates, what is the fact, that there is hardly any tangent on the upper portion of the Mexican Railway grade, whereas on the upper third of the line, shown on Plates LXXXIV and LXXXV, 41½ per cent. of the line is tangent (the average tangent being 96.3 meters or 320 feet), and on the whole 54 kilometers which have been engraved 48 per cent. of the line is tangent. The comparative degrees of curvature cannot be given.

Distance.—The distance between Vera Cruz and San Marcos, where the two lines as actually surveyed connect, was just 20 kilometers (12½ miles) longer via the Jalapa Line, viz. 262 against 242 kilometers. Had the purpose in view been the same however, merely to get to Mexico, this difference might have been more than eliminated, as will be clear from the dotted line above San Marcos on Plate LXXXIII.

Gauge.—The Jalapa line was intended to be laid to 3-feet gauge, corresponding to the gauge of the Mexican National Railway, whereas the Mexican Railway was 4 feet 8½ inches gauge. No difference was made in the location however on account of the gauge, the road-beds having been taken as 14 and 18 feet, slopes 1 to 1 in cuts and 1½ to 1 in fills, and rails estimated at 56 pounds. The ties were estimated at $1 each, only 7 feet long, which was the only item estimated in any way lower because of the gauge.

Cost.—In Table No. 1 is given an abstract of the large estimate blank prepared from the careful paper location of the entire mountain grade. Table No. 2 is an abstract closing a report by the topographer, giving in detail the material on the line, from which, in connection with Plate LXXXV, its very favorable character will be seen. From these and the maps and profiles submitted, which even in the reduced engravings show the estimated quantities at each point, any engineer can form his own judgment as to whether the estimate in Table No. 1 is adequate. The writer's belief was, and still is, that it is entirely adequate, and if so the cost of the entire mountain grade, with 30 per cent. added for en-

gineering and contingencies, amounts to less than $40 000 per mile, against $184 677 per mile for the actual cost of the mountain grade of the Mexican Railway, or in the ratio of 1 to 4½. A ratio of 3 to 1 is believed to be the very lowest which could be claimed to correctly represent the relative work. Unfortunately the writer was never able to obtain exact figures of the quantities on the Mexican Railway. Therefore he is reluctant to claim more than is certainly just.*

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* The general route of both lines here described is shown on Plate LXXXIII. On Plate LXXXIV is given a reduction to one-fifth scale, or $\frac{1}{50\,000}$ (1⅓ inches per mile, within 1 per cent.) of the large topographical map on a scale of $\frac{1}{10\,000}$ of the upper 54 of the 117 kilometers of the mountain grade. This in turn was reduced from the original field sheets on the large scale of $\frac{1}{1\,000}$ or 83⅓ feet per inch, which the difficult character of the work made necessary. The topography was very accurately taken by a skilled topographer, Mr. Max Chapman, M. Am. Inst. M. E.

On Plate LXXXV is given a photographic reduction of the original profile, which was called off, station, by station in the usual way from a paper location on the original field sheets, and estimated, station by station, from tables, with allowance for surface slope, which often more than doubled the level section quantities. The estimated quantities for each cut and fill are given on the profile and nature of material indicated. Retaining walls were estimated for at every point where a fill would not catch and are indicated by a thick line on the profile. The small amount of masonry is due to the almost entire absence of surface drainage and running water, as elsewhere noted.

The line, profile and estimate here shown were not finalities, but prepared for a special purpose. Compensation for curvature had not yet been introduced. It was fully expected to do still better at points, and in fact the location shown was greatly improved in the upper section (9) by a new line, run just before the suspension of work which threw the line back from the ragged cliff-work near the summit. As maps and profiles of this improvement cannot be given, no claim in respect to it is made, but only for what had been actually secured and recorded in black and white.

TABLE No. 1.

Abstract of the Detail Estimate of the Mountain Grade of the Jalapa Line, by sections subdivided according to the character of the work.

		Sections shown by accompanying map and profile beginning from summit.			Lower part of mountain grade.			Total of mountain grade.
No. Section		9	8	7	6	5	4	4 to 9
Length, Kilos		19	15	20.5	24.4	14	17.1	110.0
	Price.							
Earth	$0 20	$46 275	$48 649	$157 441	$87 326	$78 005	$38 649	$456 345
Loose rock	50	.....	.....	.....	.....	13 093	.....	13 093
Solid rock	1 50	284 744	56 527	.....	.....	.....	.....	341 271
Excess found	75	450	338	519	1 055	1 426	300	4 088
Total excess	.....	331 469	105 514	157 960	88 381	92 524	38 949	814 797
Tunnel	90 00	6 300	.....	.....	.....	9 000	.....	15 300
First-class masonry	10 00	1 715	4 600	5 600	3 920	16 920	1 360	34 115
Culvert "	7 50	1 710	2 902	990	4 665	3 075	1 950	15 292
Retaining wall "	4 00	63 444	.....	.....	.....	.....	.....	63 444
Paving "	3 00	210	180	345	444	852	171	2 202
Viaducts	Estimate.	19 680	.....	24 850	.....	53 803	.....	98 333
Bridges	.....	.....	3 564	.....	.....	.....	.....	3 564
Total to sub-grade		$424 528	$116 760	$189 745	$97 410	$176 174	$42 430	$1 047 047
Per kilometer		22 344	7 784	9 256	3 992	12 584	2 481	9 519

Average for 54.5 kilos.....	$13 414	55.5 kilos. ave.	$5 694	$9 519
Track and ballast per kilo.....	6 773		6 773	6 773
Total per kilo.....	$20 187		$12 467	$16 292
Total per mile.....	32 483		20 063	26 220

Total for mountain grade complete, 110 kilos. (68.35 miles.) $1 792 100 = $26 220 per mile.

Not including engineers, contingencies, shops, sidings, telegraph, etc., 10 per cent. was allowed for engineering, 20 per cent. for contingencies, and $224 000 between Vera Cruz and Puebla for the other items, the whole increasing the above sums by about 35 per cent., or to an average of $35 392 per mile, excluding rolling stock.

Notes as to Material.—Earth.—The material is invariably good, dry earth almost wholly free from stone.

Loose Rock.—None occurs, except in Section 5. Much of the lava on the upper sections is really loose rock, but is classed as solid.

Solid Rock.—After passing below Section 8, the material is all earth except a small amount of loose rock. On Sections 8 and 9 the material classed as rock is mostly porous lava, which is largely loose in pieces of 1 cubic meter or less.

Tunnels.—The upper tunnel (100 meters) is in hard white rock, the lower (70 meters) is in a soft chalk-like volcanic material. The price of $90 per lineal meter is ample.

Masonry.—The amount of masonry is very small, from the fact that no considerable drainage is encountered on the lower section, the line being chiefly a ridge line, and on the upper section the soil is so porous that no considerable water flows on the surface, as is shown by the culverts in the *camino real*, mostly just above the line. Good stone and lime exist on the spot in Sections 5, 8 and 9 where most of the masonry is. For the remainder the haul will in general not be long.

Viaducts.—Seven in all were required, aggregating 785 meters, the price being estimated for each separately. Only two short bridge-spans (9 meters—30 feet each) are required on the whole mountain grade, apart from the viaducts hardly any running water being crossed.

Tracks.—The best material for ballast was readily accessible. Rails weighing 56 pounds per yard were allowed for, at $60 per ton. Mezquite ties, 7 feet by 6 inches by 8 inches at $1 each. Joints, $1 25. Ballast, 1 610 cubic meters per mile, at $1. Laying track, $644 per mile.

TABLE No. 2.

Statement of Distances on the Line, and Kind of Rock and Other Material Passed Over.

[Prepared by Max Chapman, M. Am. Inst. M. E., Topographer of Mr. Elliott's party, accompanying a detailed report on the material encountered on the line, deposited with other original papers with the Society. The stations specified on the map are 100 meters long, as shown on the engraved profile, Plate LXXXV. Ten of them make a kilometer; 16+ a mile. It will be seen that the amount of material estimated as rock is somewhat larger than this table indicates.]

From Station	To Station	Kind of Material Encountered.
0	1	Heavy loam, clay and sand.
1	23	* Argillaceous chistose sandstone (soft).
23	26	* Argillaceous chistose sandstone.
26	56	Loam and clay.
56	70	† Massive conglomerate sandstone.
70	81	Loam and clay.
81	85	Lava (recent flow).
85	93	Loam.
93	115	† Syenite and granite.
115	146	† Syenite, granite, porphyry and basalt.
146	156	† Limestone.
156	162	Lava.
162	183	Limestone.
183	209	‡ Limestone and basalt.
209	246	§ Lava (ancient flow).
246	300	§ Lava.
300	358	§ Lava (ancient flow).
358	372	Loam and clay.
372	377	Syenite in ridges (not exposed directly on line).
377	417	Loam, clay, sand and gravel.
417	420	Loam, clay, sand, gravel and sandstone.
420	520	Loam, clay, sand, gravel, basalt and sandstone.
520	582	Clay, gravel and basalt.

* Estimated to be overlaid with an average of 1 meter of soil.
† Estimated to be overlaid with an average of 2 meters of soil.
‡ Estimated to be overlaid with an average of 3 meters of soil.
§ On this long distance of 15 kilometers (as also more or less on the above sections), the rock was estimated according to circumstances. At points the lava was exposed; at others deeply covered with soil. In the hollows, or by going a short distance at almost any point, earth for making fills could be obtained. The line was therefore carried chiefly in fill.

Summary.

	Stations.
Loam, clay, sand, gravel, etc.	274
Basalt overlaid with 3 meters of earth	26
Basalt, lava, etc., overlaid with 2 meters of earth	77
Ancient lava overlaid with 1 meter of earth	149
Soft sandstone overlaid with 1 meter of earth	25
Exposed rock, lava	10
Limestone	21
Total (extending 32 stations below limits of engraved profile)	582

Make what allowances one will, there is a great contrast in these two lines, and it therefore becomes of interest to consider how this latter line was obtained.

In March, 1881, the writer was engaged by the Mexican National Railway Company to act as engineer in charge of location and surveys on the various lines for which they had concessions, extending from the City of Mexico to the United States and to the Pacific Coast. On landing at Vera Cruz, with a large staff, under orders to report in Mexico, he was surprised at the receipt of a letter of instruction to the effect that a corps were engaged in examining a line from Vera Cruz to Mexico via Jalapa, and that he should detach another corps for service on this line, sending forward the remaining parties by rail; that he should then make a reconnaissance "sufficient to determine the general possibilities of the route, taking such escort as might seem necessary;" set the new and old parties at work; and not delay date of report in Mexico "more than six days."

To one landing in Mexico entirely ignorant of the language and the country; provided with no map or profile of the existing line, and knowing nothing more of its character than the general fact that it was one of the heaviest and most costly railways in the world; unaware that its engineers had even given a thought to a route via Jalapa, or even that there was such a place, until he finally learned that the route had been examined only to be abandoned, and that the branch which had been built to Jalapa, at the foot of the mountain proper, had 10 per cent. grades, and was practicable only by horse power; unaccustomed to a tropical climate and to the saddle; provided with no map of the region better or much larger than Plate LXXXIII which accompanies this paper; and innocent of all knowledge as to how large an escort would insure safety, if indeed any could—these were sufficiently formidable instructions, and could never have been successfully carried out, as fortunately they were to the letter (barring two days' delay from an unseasonable rain), had reconnoitering such lines been in fact so entirely lawless a matter that there was nothing for it but to look over the whole country and then decide what to do, or at least to try for.

The line which was found to be under examination is indicated by dotted lines on the general map herewith, and was at once rejected as impracticable and absurd. It ran from the coast northeasterly to Jalapa, 4 500 feet; then descended southerly, 850 feet in about 10 miles, to an

elevation of about 3 650 feet at Coatepec; then was expected to ascend somehow, some 7 000 feet, to the "pass" between the volcanoes of Orizaba and Perote, at an unknown elevation, estimated at 10 700 feet, in an air-line distance of some 15 miles; and then to descend some 2 000 or 3 000 feet, on the back slope of the mountain, to the general level of the plateau. Very naturally the best grades which it was even hoped to obtain were those of the Mexican Railway, or 4 per cent. uncompensated.

It was at once clear that either something considerably better than this must be obtained, or the line should be reported as impracticable and the whole staff withdrawn. And it seemed equally clear to the writer that either a considerably better gradient than on the existing line must be obtained, and lighter work as well, or the project reported as undeserving of any consideration financially. A reasonable hope for a maximum grade of not over 2½ per cent. at most was therefore fixed upon as the highest one justifying setting parties at work on it, and hence to be considered at all; and this, to make the project a meritorious one, required that 2 per cent. should be sought for. This made it indispensable to gain considerable development for the ascent, and this in turn made it out of the question to ascend between the two volcanoes, even had the saddle between them been cleft down to the level of the main plateau, which was known not to be the case. The whole problem therefore turned upon the question of whether or not it would be possible to turn northward at Jalapa (assuming that point to have been successfully reached by the required grade, which seemed a minor question) and run parallel with the coast line and the coast range, gradually ascending with all possible development, and turn the mountain of Perote to the north.

This possibility the writer was satisfied would turn, negatively at least, upon the simple question of whether or not there was some kind of an established highway ascending from Jalapa to the plateau, following in a general way the same course, and turning the mountain to the north. That is to say, the existence of an highway would not prove the line was practicable, but the absence of it would go far to prove that it was impracticable. In respect to highways, the writer had even then learned by sad experience, and had repeated occasions in the next three years to realize still more fully, that the route of an highway is ordinarily the worst possible guide for a locating engineer, except as

it may serve the negative purpose of a danger sign to warn him away. He now recalls no less than twenty-three instances on the lines in Mexico under his charge where the existence of a traveled road proved merely a snare to deceive. Some of these instances were of a very curious character and of much technical interest, but description must be forborne.

But in regions of real difficulty, where the elevations to be surmounted become serious even for animal power, and even after all avoidable rise and fall has been eliminated, the case is different. The writer's experience and conviction is that in such cases the aggregate intelligence of the cows and the natives thereabout may safely be trusted to discover and utilize the very best route there is for surmounting the elevation with the least amount of work. Even what would be regarded in Mexico or Colorado as so simple a problem as that of making the 900 feet rise over the Allegheny Mountains in Pennsylvania is a case in point. The pass above Altoona and Hollidaysburg was discovered and utilized in the very earliest days of the settlement of the country, and four generations of engineers on four successive public works have been able to do no better.

The first question asked by the writer, therefore, after learning the details of what was doing, was whether there was a traveled highway turning the mountain to the north, the map before him not extending far enough north to show that region distinctly at all. He was informed at once that there was, and a very old and good one. Had the response been otherwise, he should have regarded the result of the reconnaissance as practically decided then and there. The statement was coupled with another, however, that this route had been examined by the engineers of the Mexican Railway, and reported far less practicable than the line afterwards adopted and built, so that the middle line described was under examination as the only hope left.

This was discouraging enough; but on further learning that the highway had been for three centuries preceding the railway era the leading one between the interior and the coast; that there was no succeeding descent, but rather a gentle rise in it for many miles after the mountain grade proper was surmounted; that the summit was (this afterwards proved an error) several hundred feet lower than that of the Mexican Railway; and some other facts which seemed hopeful, there appeared to be a fighting chance, which was at least the only chance, that the line might be developed to give the requisite grade.

The more immediate question became then to make the ascent of 4 500 feet to Jalapa, and it was at once apparent that to have any hope of doing this on such favorable grades as were alone worthy of consideration under the circumstances, the line must be carried down to as low an elevation as possible, parallel with the coast and the mountain slope, by running south from Jalapa toward Coatepec before beginning to lose distance by turning eastward to the sea. It appeared probable that the 850 feet of fall between these two points, as to which some definite knowledge was available, could not be made on a steeper grade than 2 per cent., and it was this fortunate fact (as it proved) which first led to conducting the reconnaissance from the beginning on the fighting chance of obtaining a 2 per cent. grade.

It was now determined, therefore, that the line, if there was to be any, must pass from Vera Cruz to Coatepec, and thence to Jalapa, instead of to Jalapa direct. Coatepec lies at the head of a river of considerable size, the Rio Antigua, which runs from it directly east to the coast; and the map and known elevation of the town made it at once clear that there was no physical impossibility in descending this valley directly on a 2½ per cent. grade, or perhaps less, if the valley had a tolerably uniform descent. It needed but the most moderate knowledge of the general laws of topography, however, to make it practically certain that no even approximately uniform descent could be hoped for in a river flowing in a deep gorge, cut through what was practically only a narrow footing to the most tremendous mountain slope on this continent. The foot-hills of a slope which reached a height of 17 873 feet and started practically from the level of the sea, was certain to have, like all such slopes, a decidedly concave profile.

Nothing less than 5 per cent. could be rationally hoped for in following the bed or immediate slopes of the valley, and it therefore became quite certain that the line descending from Coatepec must start from the lowest point at the head-waters of the Rio Antigua which it was possible to obtain, but speedily rise up on the higher slopes of the valley and out of the influence of the stream, until at last—and probably within a short distance—it would rise above all supporting ground. No resource would then remain but to turn across northwardly, at some favorable point on the dividing ridge, into the valley of the next river to the north, the Rio Chachalacas, with the view of gaining only such limited development as might be necessary to catch upon some high point on what

were known to be the gentle slopes of the lower valley of that river, from which the line could descend eastwardly on the required grade to sea-level at a point as near to the coast as possible. The only fear in this process, besides the danger of heavy work, was that it might be unavoidable to make a long horse-shoe development up the valley of the Chachalacas, bringing the foot of the grade far inland from the sea, and causing just so much unnecessary loss of distance on a level before reaching the foot of the mountain grade. The existence of these two parallel and deep lying streams made it certain that the general scheme below Coatepec would be practicable, if not too costly; and the immense depth of the southerly valley, which varied from 1 000 to 2 000 feet, together with the absence of all supporting ground to the south of it, made it certain that the line could at no point turn south between Coatepec and the coast.

Thus, by a process of exclusion, the entire line was projected and sketched upon the map, with most dismal apprehensions of the character of the work which would be encountered, but with absolute confidence, expressed at the time to the gentlemen who accompanied the writer on reconnaissance, in the face of some opposition, that if this line was not practicable, there was nothing in the region which was sufficiently defensible, from an economic point of view, to make it even worth examination. The line shown on the general map (Plate LXXXIII) which the writer now has the honor to lay before the Society, does not differ by its own width at any point in the entire ascent of nearly 8 000 feet to the plateau from that which the writer thus sketched upon the map in the City of Vera Cruz, and showed to several gentlemen, on the evening of the day when he first landed in Mexico; within two hours after first learning that there was such a place as Jalapa, or that there was, or ever had been, such a project as an ascent to the plateau through that region, and with the elevation of only two points on the line, Jalapa and Coatepec, approximately given. Neither does the line on Plate LXXXIII differ by much more than its own width at any point from the position of the line as finally surveyed, as shown on the detailed maps and profiles which are herewith laid before the Society complete, the more difficult upper half of the mountain grade only having been engraved on Plates LXXXIV and LXXXV.

The writer would not be understood to assert or imply that equal positiveness in defining in advance the limitations of reconnaissance is

often possible. On the contrary, he has never known another instance just like it, although it became his duty later to consider projects for several other lines of a similar but less exacting character. But the peculiar conditions, it will be seen, left no escape at any point from the chain of reasoning. Had there been no existing parallel line, one might have justifiably taken the region for better for worse, and borne with equanimity finding it a great deal worse than he took it for. As it was, the fighting chance for a low grade was the only one economically worthy of attention, and this primary fact given, the conditions left no escape at any point from the train of reasoning that it was that one route or nothing.

The next morning at daybreak the reconnaisance began, and was pushed through with increasing confidence as fast as the animals could stand it, or at the rate of some 40 miles per day, the entire examination of the mountain grade occupying three days—such haste being merely in fulfillment of the writer's positive instructions, and naturally against his inclination. Less time was required, however, because the only real purpose of the reconnaisance was not to find a route, but to examine on the ground the features of what was already known to be the only route affording a rational chance of success. The first 1 500 feet of rise was seen to be on slopes smooth in detail, but sufficiently steep for laying down a surface line on almost any grade, and were not examined critically. The dividing ridge was then followed up, to judge of what was really the only critical point of the lower descent (from the point of view of possibility and not of cost), the passage from one water-shed to the other. A long and sharp spur ridge running eastwardly from Coatepec about half way to the coast, having a crest 5 000 or 6 000 feet high, and standing at right angles to the main slope, was found to define the point where this passage must occur pretty definitely, and the material and topography was seen, with much relief, to be favorable for making this passage with as much or as little development as might be necessary, with considerable latitude in elevation and easy work. The south slope of this mountain, where the line would lie, was found to be almost impracticable for passage on horseback without camp equipage and time; but observing the north side to be fairly favorable, and taking it to be very unlikely that, in a ridge of this character, the topography would differ widely on the two slopes, it was passed by with a confidence that the result fully justified, as well as such very limited

information as was available at the time. It will be seen from the maps and profiles of this section (not engraved) that on the surveys now submitted, a few of the most costly single works on the line are here, and not on the engraved section above Jalapa, which was really the critical section. This, however, the writer is, and was then, satisfied was due chiefly to the fact that the lower section, not being a source of much anxiety, was left in less competent hands. In part it was radically improved almost at the conclusion of surveys, and the writer feels no doubt that it all might have been more or less, although he makes no claim in that respect. Owing to the falling away of the country to the south, before referred to, and the existence of the deep *barranca*, or gorge, in which the river lay, which cut down almost to sea level, or some 3 000 feet below the line, some of the most sublime views of the line were on this section; but its difficulty was not in proportion, in part because of the very fact that the line lay so high as to be above the immediate influence of the *barranca*. The material on all this section was exceedingly favorable.

The region between Coatepec and Jalapa was known to be not very rugged, and to oppose no difficulty as to elevation, so that it also was passed by with a confidence which the result justified, and the project was complete to Jalapa, as a basis for surveys, with a reasonably favorable 2 per cent. grade line all but assured.

For the critical section above, the distance by highway was found to be almost one-half too short, and all hung upon the possibilities of development. The material and topography on the lower half was found to be favorable for this purpose, being earth to a great depth, as noted, and sufficiently broken up by ridges and hills. A long stretch at about the middle of the slope, near the village of San Marcos, was of an equally favorable character, being literally an inclined plane on a slope of about 1 in 10—an old lava flow overlaid with soil—and not much broken up in detail. The upper section was rugged, but short, with considerable opportunities for rather expensive development.

The whole of this region was examined on the third day of a very heavy rain-storm, the end of which could no longer be waited for, and the examination was necessarily restricted to salient features only. On a long grade line of this character, however, the possibilities of developing on practicable ground to reach certain elevations at certain fractional portions of the available distance, can be judged of with some certainty, the general character of the slope being the main feature; and

the writer felt no real doubt then, or at any later time, that a grade in the neighborhood of 2 to 2½ per cent. was easily practicable, there being a certain considerable belt of favorable territory on which to place it, although above and below that the topography was much more forbidding. A leading factor in reaching this apparently hasty conclusion was the splendid and ancient highway already referred to, by far the best in Mexico, if not on this continent. It is a broad macadamized road with paved gutters, and a stone curb or masonry wall at the side, and the writer desires to pay a tribute of admiration and respect to the unknown engineer, whoever he was—very possibly one of the soldiers of Cortez, or one of his immediate successors—who laid it out. From a point near Jalapa to the summit, near Las Vegas, there is not a break in the steady ascent, and there are few points on it where a fresh team of horses would not readily break into a trot. The conclusion was natural, that if a Spanish soldier in 1530 could put something like a 6 per cent. highway down that mountain slope, an American engineer in 1881 ought to get a 2 per cent. railroad line down it, or take off his hat to his predecessor.

After reaching the summit, the continuation of the line to Mexico, or any other point on the plateau, was a detail offering no difficulties and needing no immediate study. The line was therefore reported on in writing to Mr. W. C. Wetherill, chief engineer, three days later (March 28th), as follows:

"The line under examination was too forbidding to be worth further attention. * * * I feel no doubt that the proper place for the line is to the north of Perote, and that something like a 2½ per cent. grade, or possibly a 2 per cent. grade, is practicable above Jalapa. Whatever grade is there obtained can certainly be continued down to sea-level and slope without excessive work. I have instructed surveys to be conducted above and below Jalapa on a 2 per cent. basis for the present, and consider the prospects for a fairly favorable line good."

It should be mentioned further, that the writer's examination had been merely in a consulting capacity (the line not being formally a part of the Mexican national projects), and for some months later he had no permanent connection with or knowledge of the progress of the work, being absent on the Pacific slope. On being again asked to examine the line, August 1st, 1881, he found that his conclusions had been reported on as impracticable, and that a 3 per cent. compensated

grade had been adopted, located in part, and was under construction.* Fortunately however, a most intelligent assistant engineer, of great natural capacity for location, Mr. John S. Elliott, was in charge of the upper locating party. To his admirable conduct of surveys the success of this line was very largely due. Aided by information he had acquired, it was soon discovered that the abandonment of the 2 per cent. grade had been an over-hasty conclusion, from data which in fact assured its success. The work in progress was therefore stopped by the writer's advice; some $30 000 of completed work abandoned, chiefly in the approaches to a costly tunnel in earth; and the writer appointed chief engineer, continuing in charge until some time after the completion of the surveys now laid before the Society, when the abandonment of all furtherance of the project by the Mexican National Railway compelled his resignation, and shortly afterward led to the stoppage of all work. But for the fact that he was favored with an unusually competent assistant in immediate charge of surveys on the more difficult section, the writer fears that he should never have been able to carry through the line with the limited time at his command.

Two features on the upper ascent are worthy of special note: One, the great lava flow shown on Plate LXXXIV, and before referred to, and the other, a still grander feature, the *barranca* of Zimilahuacan, a vast sink-hole in the earth some 2 or 3 miles in diameter, and some 3 000 feet deep by the barometer, about half of it sheer, with no transition or "ragged edge" whatever from the surrounding surface of the plateau, which was as smooth and treeless as an Illinois rolling prairie, but sloping about 1 in 12 or 15 in the chasm. This feature was encountered some miles beyond where all difficulties had ceased at the summit, and so smooth was the edge that the line skirted it with a mere surface line, so near to it that a stone thrown from the car window would fall sheer full 1 000 feet before touching. On the plateau the locality was so cold and so much exposed that it was stated that wheat would hardly head, while immediately beneath one's feet bananas, coffee, oranges and every form of tropical vegetation could be seen growing luxuriantly. A few miles beyond was a large and very ancient fortress still in good repair, but unoccupied, which would cost perhaps $5 000 000 or $6 000 000 to duplicate, in which for two centuries the great bulk of the silver pro-

* The concession permitted of no delay in beginning construction.

duct of Mexico was stored pending the arrival of transports at Vera Cruz. Several of the old line of visual telegraph towers which were used to communicate between the two points are still pointed out, although out of use more than a century. From several points on the upper ascent the City of Vera Cruz, 80 miles off in an air-line and 6 000 to 8 000 feet below, is visible in clear weather. These and other features make the region one of the highest interest to the tourist.

A line of almost equal engineering interest was located by the writer from the Pacific Coast at San Blas to the plateau, which he regrets that he cannot extend this paper further to describe. In Plate LXXXVI is shown its most interesting single feature, a bridge spiral, some of the details of which are shown in the notes accompanying the plate, and which was believed at the time to be the only bridge spiral in the world. Another one, however, on a smaller scale, had even then been located on the Georgetown, Breckenridge and Denver Railway, and has since been completed. It is as yet the only one completed, the construction of the Pacific Branch located by the writer having been suspended for lack of funds.

In view of what has preceded, the writer hopes that he may not be suspected of over-estimating the difficulties of securing such lines, or of personal inability to cope with them, when he declares his conviction that this whole method of taking railway lines up difficult ascents by a continuous succession of curves and tangents on a rising grade, over which the locomotive keeps up a steady march, is fundamentally wrong and bad, and one which might profitably be modified in nearly all cases when an elevation of over 1 000 feet, or possibly much less, is to be surmounted. To furnish a suitable background for the expression of these conclusions, by showing that they are formed in spite of fairly successful experience in following up the more usually approved plan, is a main purpose of this paper.

Three general methods for surmounting such elevations, besides the almost universal one, are more or less in use:

First.—Rack or grip railways.

Second.—Inclined planes operated by stationary engines.

Third.—Switch-backs.

The first of these was proposed in a practicable form over thirty years ago, and the two latter ante-date the locomotive itself. Either one of them is probably deserving of more use than is given it, but the third

(switch-back) the writer deems worthy of adoption by engineers as the standard plan for surmounting considerable elevations, always provided the switch-backs be constructed and operated in quite a different manner from that usual in the few which exist, which have for the most part only been resorted to as a last resource.

One feels a natural hesitation in expressing a conclusion which, it must be admitted at once, all the tendency of modern practice tends to discredit. The accumulated verdict of experience is rarely wrong, and it is undeniable that all these plans have been in many cases tried and abandoned, and have met decreasing favor. Nevertheless, causes needless to go into, other than lack of real merit, may explain in part at least this result, and the writer sees no escape from believing that they do so wholly.

The various forms of rack or grip railways have never yet won marked success for other than scenic lines of light traffic, where economy of operation was no great object. The most promising effort in this direction, by far, is the Abt system, recently described by Mr. W. W. Evans, M. Am. Soc. C. E., in a paper before this Society, which certainly has features of striking merit which will lead engineers to watch its progress with great interest. Among these are the rack with stepped or staggered teeth; the compound gear-wheel engaging therewith, with its peculiar elastic adjustability, insuring even bearing of the cogs on the rack at all times, and, above all, the admirably ingenious footing to the rack, by which a locomotive working by ordinary traction may approach the foot of the rack grade at ordinary working speed, retaining all its momentum, and leaving the adhesive traction cylinders still working, with certainty that the rack gear will engage smoothly and without shock, and work conjointly with adhesive traction thereafter, thus removing the most serious theoretical objection to the locomotive, that it is unable, except within a very limited range, to increase the tractive force exerted by it at the expense of speed. But with all these merits the apparatus is rather costly, both for maintenance and renewal, and its range for profitable employment must be limited.

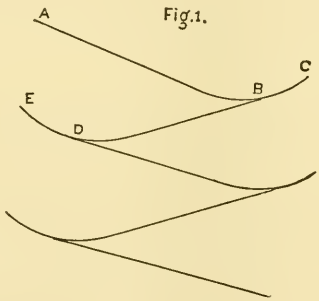
The capabilities of the inclined plane or cable plan have been greatly extended in recent years, as applied to street and local passenger service, and it is clearly destined in the near future to still wider use. Superficially, the record of its use in connection with ordinary railways is most discouraging to any hope of its future usefulness in that direction.

In the early days of railways it was constantly considered, and often used. A complete plant of the kind existed over the Allegheny summit of the Pennsylvania Railroad before that line was built, and was abandoned in favor of locomotive traction, even to connect two lines of canals. Several complete railways operated by successive inclined planes and gravity inclines were built in Pennsylvania and elsewhere—two in Northern Pennsylvania of considerable length, one of which is still in use and the other only recently abandoned, but not chiefly, if at all, for reasons affecting its abstract merit. It is not generally known that the existing main line of the Pennsylvania Railroad over the Alleghenies, which was built long after the old planes had been abandoned, was laid out with the distinct view of afterwards adding a new and enlarged system of planes for freight traffic when the volume of traffic had increased to justify it. This policy was favored by its distinguished chief engineer, Mr. J. Edgar Thompson, and some elaborate and interesting data in respect to it are given in the early reports of that road, notably in a report by the then Superintendent, Gen. Herman Haupt, in which the ground is distinctly taken that it is a mere question of volume of traffic whether inclined planes are economical or not.

That view the writer apprehends to be the true one. The fixed tractive plant is costly to construct, maintain and operate, and expenses are not greatly affected by whether the tonnage moved by it be large or small. It by no means follows that, because the system was wisely abandoned in favor of locomotive power, for the thin traffic of those early days, that it is wise to continue to neglect it at points where almost a steady stream of laden cars is to be carried, first up and then down a dividing ridge, day and night, the year round, as on the Pennsylvania summit, and at many similar localities. At such points it is demonstrable that not only may the great amount of power used in lifting locomotives be saved, but that the descending and ascending cars may be balanced against each other, thus largely eliminating the effect of the rise; while the superior economy of stationary engines will largely reduce the cost per horse-power, after allowing for the friction of cables, which, on a short, steep incline is a minor element. Especially now that the making of long continuous cables is so well understood, so that as long an incline as the topography permits may be readily worked, it is worthy of the most serious study whether a very large economy is not

readily possible at such special localities, a considerable number of which may be counted up.

A proper switch-back system, however, seems to the writer the most generally useful and meritorious for lines of probably thin traffic, as well as the most unquestionably practicable for use in all such localities. The germ of the proper system was contained in the first switch-back laid out in America, if not in the world—that at Mauch Chunk—which was used for dropping empty coal-cars down into the Nesquehoning Valley, before the tunnel of that name was completed. That track was used only for cars passing in one direction (descending), and was operated as follows:



The cars were started from *A*, Fig. 1, on a down grade of about 1 per cent., calculated to give a considerable velocity. At *B* an automatic switch, whose exact mechanism the writer cannot give, was run through and the car brought to a rest by the next succeeding up grade at *C*, from which it immediately started back towards *D*, passing through the switches *B* and *D* until again stopped at *E;* and so on indefinitely, the cars descending several hundred feet in all without the slightest attention, very rapidly, with very rare accidents, and with no one on them or stationed along the track.

Thus, to say the least, every advantage was gained that could have been gained by a long continuous descent, with the immense advantage that, owing to the entire liberty of choice as to the length given to each plane, the best alignment and lightest work available on any part of the surrounding country may be chosen.

But more than this was gained. Any long continuous grade which is steep enough to move cars with journals in rather bad order, must be steep enough to speedily give cars in good order a dangerous velocity.

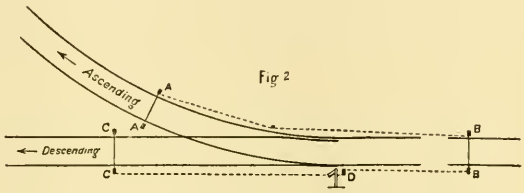
Thus, it would be impossible to let cars run of themselves down a continuous grade of any kind, while, on the switch-back, not only was this very readily done, but a pretty high average velocity could be safely used, from the fact that it in any case could not exceed a certain maximum. Again, when necessity required, it was easy to stop cars at any point.

Analogous advantages are readily obtainable, *mutatis mutandis*, by switch-backs operated by regular trains running in both directions, but not under the conditions of ordinary practice, which necessitates the complete loss of all the *vis viva* of the train at every switch. The plan shown in Figs. 2 and 3 will apparently obviate this necessity completely, and introduce no new elements liable to cause difficulty, but, on the contrary, give smooth, easy and rapid motion. The details of this plan are as follows.

As Respects the Switches.—The switches should be, and are easily made, entirely automatic. Their normal position should be that in Fig. 2, in position for running up hill, and not down hill. A runaway train or car cannot then pass a switch and continue down grade. As respects a train going up grade, this arrangement presents no difficulty. It may simply run through the switch *D*, springing the points over to let the wheels pass. Simple devices of many different forms may be used to restrain too rapid return of the points after the passage of each single wheel, but this is not essential, as the wear and tear would be small.

A train descending should be able to operate the switch, so as to continue descent, by a single act of the engineer, but only by intention on his part. This may be accomplished by a very simple and inexpensive apparatus, such as that outlined in Fig. 2, operated by a lever or idler wheel on the locomotive controlled by the engine-man, and with mechanism somewhat similar to that of the simpler forms of interlocking apparatus, which it would be superfluous to describe in detail, as it can be designed in a few hours by any signal engineer. The general method of operation is described below Fig. 2, the whole insuring that (1) up trains shall always pass the switches freely and automatically; (2), that runaway down trains shall never pass them, but be caught; (3), that regular down trains shall be enabled to pass the switches automatically by a single act of the engineer; (4), that careless neglect of this act shall do no other harm than to cause the train to run back again on the up track; (5), that danger signals shall be set when

the switches are wrong, or any part of the apparatus broken; (6), that the switches can at all times be operated by hand if desired, or if the mechanism is out of order.



MECHANISM FOR AUTOMATICALLY OPERATING THE SWITCHES OF SWITCH-BACKS.

The mechanism here outlined acts as follows :

DOWN TRAINS.—*A* places *B* and *C* in position to act, which are otherwise entirely inoperative.

B, when first made operative by *A*, opens the switch *D* for track *C*, and holds it open.

C, always operative when *B* is, returns *A*, *B* and *D* to their original positions.

A, *B* and *C* are supposed to be located with reference to having the engine always at the same end of the train. If the engine be at the other ends the switches must be operated by hand.

UP TRAINS.—If, by carelessness, the engineer of an up train should leave the switch-actuating lever down, nothing will happen except to set *A* as if for a down train, in leaving the switch-back. This will not effect following trains either down or up. Should a succeeding up train be equally careless it will act first on *C* and then on *A*, thus running through the switch with no effect.

AS RESPECTS THE ADJUSTMENT OF THE GRADES.—Fig. 3 shows in detail what the writer regards as the proper adjustment of grades for a 2 per cent. switch-back, and the principle of the adjustment for any grade. With this arrangement it is unnecessary for an up train to use brakes, or even shut off steam at all, for making the stop and then starting backwards.

It will be seen that the up grade continues unbroken until it has passed the switch and then rises in a sharp vertical curve, which rises above the regular grade, slowly at first, and at the further end—merely as a precaution against accidents—rises very rapidly indeed. This is to bring the train to a stop slowly and gradually, but certainly, without either shutting off steam or using brakes. The rise necessary to do this for any given train speed may be computed exactly, and is given in the following Table No. 3 computed by the writer and not elsewhere readily accessible.*

Suppose a train to be ascending the 2 per cent. grade at a uniform speed of 15 miles per hour. Then, by the table, a lift of 7.99 feet above the regular grade will bring it to a stop even with the engine still using steam. If the velocity be only 10 miles per hour, a lift of 3.55 feet only will be necessary, and this will or can readily be made to be the usual speed of approach. In that case, if the train consist of 10 cars and be 400 feet long, it will come to rest with the steam still on, unchanged, when the rear of the train has passed a little over 100 feet past the switch, the center of gravity of the train being then 3.55 feet above the tangent grade line. The slack of the train will be taken out, under these conditions, very gradually indeed, and almost at the instant of coming to rest.

If, then, without changing the throttle, the reverse lever be thrown over into back gear, or even merely into mid-gear, so as to do no work at all, the train will immediately start backward, still holding all the slack out of the train, which will continue out until forward motion is resumed at the next switch-back. If the lever were immediately placed in the same notch of back gear in which it formerly stood in forward gear (which would be unnecessary) the speed which the train would have acquired on resuming the upper straight grade at *7*, Fig. 3, would be that due to the height *c*, which is $3.55 + (8 \times 4) = 35.55$ feet; or, as per Table No. 3, $31\frac{1}{2}$ miles per hour, an objectionably high, but not dangerous, speed. Had the velocity of approach from below been 15 miles, this speed would have been that due to 37.99 feet, or only $32\frac{2}{3}$ miles per hour, and had the velocity of approach (in case of passenger trains) been even 20 or 25 miles, this speed would have been only 36 or

* The table is taken from the forthcoming revised edition of the author's treatise on "The Economic Theory of the Location of Railways," and has likewise appeared in the *Railroad Gazette*, March 26th, 1886, "Experiments on Train Resistance."

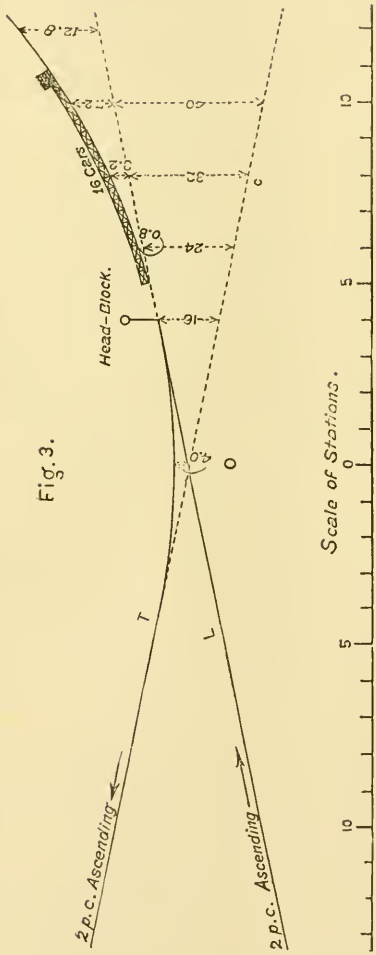

12.8
40
32
24
16
0.8
16 Cars
Head-Block.
4.0
T
L
2 p.c. Ascending
2 p.c. Ascending
Scale of Stations.
10
5
0
5
10

Fig. 3.

TABLE No. 3.

Giving the Total Energy of Potential Lift in Vertical Feet in Trains Moving at Various Velocities.—Including the Effect of the Rotative Energy of the Wheels for Passenger or Loaded Freight Trains, assumed at 6.14 per cent. of the total energy. For trains of empty flat or coal cars add about 4 per cent. to the quantities below, and proportionately for mixed trains.

Miles per Hour.	0.	Diff.	1.	Diff.	2.	Diff.	3.	Diff.	4.	Diff.	5.	Diff.	6.	Diff.	7.	Diff.	8.	Diff.	9.	Diff.	
0.....	0.00	.04	0.04	.10	0.14	.18	0.32	.25	0.57	.32	0.89	.39	1.28	.46	1.74	.53	2 27	.61	2.88	.67	0
10.....	3.55	.75	4.30	.81	5.11	.89	6.00	.96	6.96	1.03	7.99	1.10	9.09	1.17	10.26	1.25	11.50	1.32	12.82	1.38	10
20.....	14.20	1.47	15.67	1.52	17.19	1.60	18.79	1.67	20.46	1.74	22.20	1.80	24.00	1.88	25.88	1.95	27.83	2.03	29.86	2.09	20
30.....	31.95	2.17	34.12	2.23	36.35	2.31	38.66	2.38	41.04	2.45	43.49	2.52	46.01	2.59	48.60	2.66	51.26	2.74	54.00	2.80	30
40.....	56.80	2.88	59.68	2.94	62.62	3.02	65.94	3.09	68.73	3.16	71.89	3.23	75.12	3.30	78.42	3.37	81.79	3 45	85.24	3.51	40
50.....	88.75	3.59	92.34	3.65	95.99	3.73	99.72	3.80	103.52	3.87	107.39	3.94	111.33	4.01	115.34	4.08	119.42	4.16	123.58	4.22	50
60.....	127.80	4.30	132.10	4.36	136.46	4.44	140.90	4.51	145.41	4.58	149.99	4.65	154.64	4.72	159.36	4.79	164.15	4.87	169.02	4.93	60
70.....	173.95	5.01	178.96	5.07	184.03	5.15	189.18	5.22	194.40	5.29	199.69	5.36	205.05	5.43	210.48	5.50	215.98	5.58	221.56	5.64	70

Formula: Vel. head $= \frac{v^2 \text{ in ft. per sec.}}{64.32} = \frac{1\ 467^2\ V^2 \text{ (in miles per hour)}}{64.32} = 0.033445\ V^2$

To which add 6.14 per cent. for rotative energy of the wheels $= 0.002055\ V^2$

Giving as the final formula, by which the table is computed, *Vel. head* $= 0.035500\ V^2$

39 miles per hour. Thus the switch, with grades arranged as shown, can be run through at any speed, making no more change in the brakes, steam or engine, than to throw over the reverse lever, at the moment the train comes to a stop, from full gear forward to full gear back.

With ordinarily careful and safe working, the speed at *T*, Fig. 3, would be about ten miles per hour higher than the speed of approach, a gain far more than sufficient to obviate all loss of time from the stop, and equivalent (for speeds of 10 miles per hour approaching and 10 miles leaving) to a subtraction of 10.65 vertical feet from the rise in the next grade—a gain which will considerably increase the average speed or hauling capacity, or both.*

Fig. 3 equally well represents the conditions at the next ensuing switch-back, where the train approaches rear-end to it, if we simply assume the engine to be at the other end of the train. It reaches the position shown, backing up from below, with all slack out of the train. In starting forward on the up grade, the rear end of the train, being on a steeper grade than the engine, will tend to crowd slightly upon it, and by setting the reverse lever in the second or third notch of forward gear, the slack will be taken out in the gentlest possible way, far more gently than is ever possible in starting on a level.

Thus the ordinary and great objections to sharp hollows in grade lines do not apply in this case. On the contrary, the action is smoother than it would be without the curved profile. Similarly, the still greater objections to a stop on the grade line do not apply at all in this case. We rather gain by it, because the whole train stops and starts again with the gentleness and economy of energy of a pendulum, for identical mechanical reasons.

This being so—there being no loss of time, no loss of distance, no loss of hauling capacity, and no measurable loss in smoothness of motion—we have left as a net gain two things: *First*—A great additional safeguard

---

*If the train were running up a straight grade *L O T* at 15 miles per hour (say 22 feet per second) in $\frac{400}{22} = 18{,}2$ seconds.

Via the switch-back it takes:

O to stop, 800 feet at average speed of about $\frac{0+22}{3} = 48.5$ seconds.

Stop to *T*, 1 200 " " " " $\frac{0+37}{3} = 43.3$ "

91.8

Loss of time, as nearly as may be, $1\frac{1}{4}$ minutes.

The train is then moving 10 miles per hour faster, so that it will save this lost time almost within the next mile.

against collisions with and derailments of runaway trains or parts of trains. Accidents resembling the terrible one on the Southern Pacific, on the Tehachapi grade, some years ago, in which nearly all of a train-load of people were killed or injured, are not likely to occur. Before a train can attain a velocity of 60 or 70 miles per hour it must fall 128 or 174 feet in excess of the fall required to overcome its resistance. If we estimate its average resistance in acquiring that speed at 20 pounds per ton, equivalent to the acceleration on a 1 per cent. grade, a train must descend a 2 per cent. grade for 2½ to 3½ miles before it will acquire those velocities. A single car would take much longer yet, so that a switch-back every 3 or 4 miles would go far to insure against the worst results from such catastrophes, which no care can wholly avoid.

Second—A great reduction in cost of construction and amount of curvature, and usually in rate of gradient as well, is assured; in some cases more than others, but always considerable. In the line described in this paper, the writer estimates that half the curvature, and nearly half the cost of construction to sub-grade, might have been saved by using not more than eight or ten switch-backs on the whole ascent of 8 000 feet, through the better choice of ground afforded. An entirely different route would have been selected, and nearly the whole line might have been reduced to but little more than a surface line.

On the other hand, there is the unquestionable disadvantage in switch-backs, that engines do not pass curves well running backward. In part this is remediable in the design of engines, and by leaving the rear drivers blind, but the only proper course would be to use an easier maximum curve on the sections on which the engine runs backward, which would be the same both ascending and descending, and to make those sections as short as possible.

Thus, the writer believes, this objection, while it cannot be entirely removed, may be reduced to very small dimensions; and should it again fall to his lot to locate a line of railway upon an ascent of 8 000 vertical feet, or even a half or a quarter—or, possibly, even an eighth—of that amount, he will in no case willingly attempt to locate it for an unbroken locomotive run, but either use switch-backs for a light traffic, or study with great care the possibilities of the locality for inclined planes with a heavy traffic.

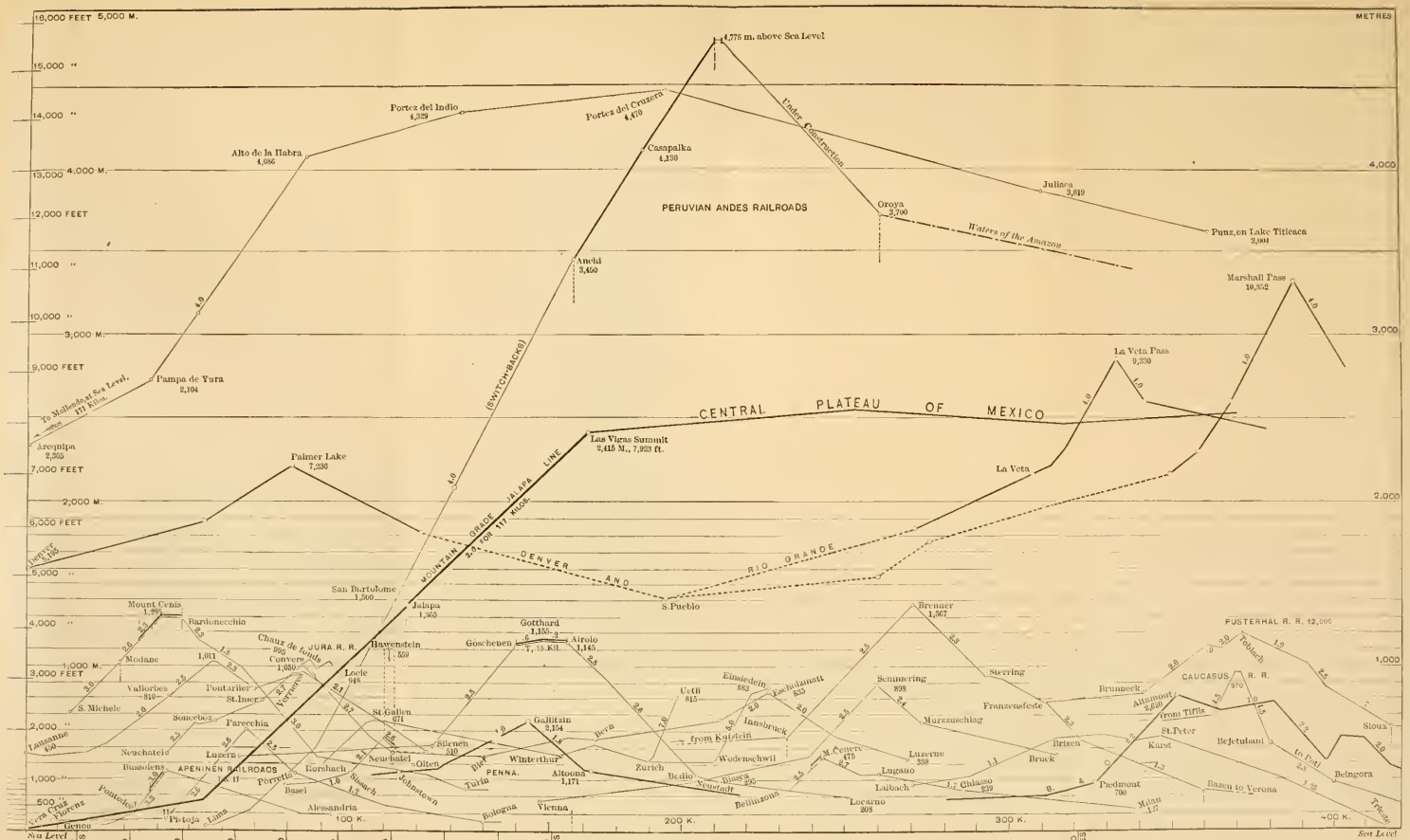

16,000 FEET 5,000 M.
METRES
15,000 "
14,000 "
13,000 4,000 M.
12,000 FEET
11,000 "
10,000 "
3,000 M.
9,000 FEET
7,000 FEET
2,000 M.
6,000 FEET
5,000 "
4,000 "
1,000 M.
3,000 FEET
2,000 "
1,000 "
500 "
Sea Level
4,000
3,000
2,000
1,000
Sea Level
10 MILES
20
30
40
50
60
70
80
90
100 MILES
200 MILES
100 K.
200 K.
300 K.
400 K.
4,378 m. above Sea Level
Portez del Indio
4,329
Portez del Cruzero
4,479
Under Construction
Alto de la Habra
4,086
Casapalka
4,130
PERUVIAN ANDES RAILROADS
Juliaca
3,849
Oroya
3,700
Waters of the Amazon
Punz, on Lake Titicaca
3,901
Ancki
3,450
Marshall Pass
10,852
La Veta Pass
9,330
Pampa de Yura
2,104
To Mollendo at Sea Level.
171 Kilos.
(SWITCHBACKS)
CENTRAL PLATEAU OF MEXICO
Las Vigas Summit
2,415 M., 7,923 ft.
Arequipa
2,325
Palmer Lake
7,239
La Veta
MOUNTAIN GRADE JALAPA LINE
3.04 TON 117 KILOS.
DENVER AND RIO GRANDE
S. Pueblo
San Bartolome
1,260
Jalapa
1,353
Mount Cenis
1,295
Bardonecchia
Modane
1,011
Chaux de fonds
992
Convers
1,030
JURA R. R.
Havenstein
859
Lodi
948
Gotthard
1,155
Göschenen
Airolo
1,145
15 Kil.
Brenner
1,367
Schmeering
898
Sterring
Franzensfeste
Brunneck
Altgmont
2,660
CAUCASUS R. R.
970
PUSTERHAL R. R. 12,000
Toblach
Stous
Bejetuland
Karst
St. Peter
from Tiflis
to Poti
Bazen to Verona
Belgora
Trieste
Piedmont
700
Milan
Brixen
Bruck
Murzzuschlag
Einsiedeln
883
Eschelmatt
825
Uetli
815
Innsbruck
from Kufstein
Wodenschwil
M. Cenere
475
Luzerne
338
Lugano
Laibach
Chiasso
239
Locarno
203
Bellinzona
Vienna
Altoona
1,171
Zurich
Bedio
Neustadt
Winterthur
Gallitzin
2,154
Bera
Silenen
510
Olten
Burkshach
Basel
Turin
Johnstown
Pontedera
Pistoja
Lima
Alessandria
Bologna
Genoa
Vera Cruz
Parenz
Tarcoma
Pontrelli
Neuchatel
Bussolens
APENINEN RAILROADS
Lucerne
Neuchatel
Lausanne
430
Soncebo
Parecchia
Valloribes
810
Pontarlier
St. Michele
St. Inaco
Modane
Mount Cenis
Bardonecchia
Denver
5,196
Palmer Lake
7,239
Arequipa
2,325
Pampa de Yura
2,104
Alto de la Habra
4,086
Portez del Indio
4,329
Portez del Cruzero
4,479
Casapalka
4,130
Ancki
3,450
Las Vigas Summit
2,415 M., 7,923 ft.
La Veta
La Veta Pass
9,330
Marshall Pass
10,852
Juliaca
3,849
Oroya
3,700
Punz, on Lake Titicaca
3,901
Under Construction
Waters of the Amazon
Piedmont
700
Milan
Bazen to Verona
Belgora
Trieste
Stous
Bejetuland
Karst
St. Peter
from Tiflis
to Poti
Toblach
Brunneck
Altgmont
2,660
CAUCASUS R. R.
970
Brixen
Bruck
Murzzuschlag
Franzensfeste
Sterring
Schmeering
898
Brenner
1,367

PLATE LXXXIV
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WELLINGTON ON
RAILWAY LINE IN MEXICO

Notes to Plate LXXXIV.

The scale shown ($\frac{1}{10000}$) below the title is for the original map from which this was reduced. This reduction was intended to be on a scale of $\frac{1}{20000}$, but by error of engraver is a little less.

The degrees of curve given are for 20-meter chain (chord of 65 6 feet), and are somewhat more than two-thirds of the degree of the curves by the foot system (100-foot chords).

It will be seen by the border that the reduction of the two halves of this plate is not precisely correct. Owing to the size of the original map, it was impossible to photograph the whole plate at once.

Owing to the necessity of carrying off the original of this map to the United States before it was entirely finished, sketched topography extending beyond the limits of could survey be added only at a few points, and the kilometer marks could not be put on. As they could not be added accurately to the map for engraving without access to the original field-sheets, it was thought best not to add them at all. The limits of the three sections (7, 8 and 9), into which the portion of the line engraved was divided for estimating purposes, may be determined by the following scaled distances, which likewise indicate the amount of distance gained by development. Starting from the point near the left-hand corner marked "Summit," we have in succession:

Section.	Location.	Length. By Air Line from Beginning to End of Section	Length. By Located Line.	Length. Increase by Development
9	Summit to end of ragged cliff work*	8 5 kilos	19.0 Kilos	100 to 224
8	End section 9 to middle of third horse-shoe curve	7.5 "	15 0 "	100 to 200
7	Middle of third horse-shoe to middle of flat, opposite Jalapa	7 0 "	20.6 "	100 to 200
		23 0 "	54 5 "	100 to 238
7-8-9	Air line from summit to Jalapa	21 5 "	54 5 "	100 to 254

* This Section, 9, as elsewhere noted, was entirely relocated at the very conclusion of surveys, throwing it back from the ragged topography shown, on higher and smoother ground, and somewhat shortening the distance which was gained by an increase of the development on the smoother ground below, where it rest low. The only tunnel on the line above Jalapa was thus taken out, and the quantities much reduced. The line had not been mapped on a small scale, nor even a precise location made, so that no details of it can be shown.

FERRO CARRIL NACIONAL INTEROCEANICO.

From VERA CRUZ via JALAPA to the CITY of MEXICO and the PACIFIC COAST.

Profile of the PRELIMINARY LOCATED LINE on the

UPPER HALF of the MOUNTAIN GRADE

from JALAPA to LAS VEGAS.

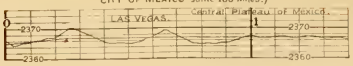
Sections 7, 8 and 9.

A. M. WELLINGTON Chief Engineer.
John S. ELLIOTT. Chief of Party, Secs 7-9

Levels are an Old Datum reading about 50,000 metres below true Elevation.
Scale of Original Profile reduced 2/3 giving the following comparison:

ORIGINAL SCALE	Horizontal 1/5000	or	417 ft per inch
	Vertical 1/400	"	33⅓ " " "
PRESENT SCALE	Horizontal 1/12,500	"	1,042 " " "
	Vertical 1/1,000	"	83⅓ " " "

PROFILE of PART OF FIRST MILE, after reaching the SUMMIT.
(Line continues of this general character for the entire distance to the CITY OF MEXICO some 160 Miles.)



Beginning of 2½ percent Grade = 2415.0 Metres above Tide = 7923 Ft Elevation, at Boca del Monte Summit on Mexican R. R. capital. (Sta 0 = 130 . 1st Station.)

Lava Flow in Barranca rushing directly to the Coast 60 Miles.

SECTION 8. SECTION 9.

the entire line lies on the slope of an old Lava Flow, porous and much shattered on top, covered with 2 inch to 5 Feet of soil.

Opposite SAN MIGUEL.

On Section 8 (From Kilo 19 to Kilo 33)

2nd Horseshoe (1½ Curve)

1st Horseshoe (1½ Curve)

SAN MIGUEL.

No surrounding ground

Below Kilo 33 there are no indications that Rock exists for a great depth below the Surface.

3rd Horseshoe (1½ Curve) 4th Horseshoe on Hill (4° to 4½ curve)

SECTION 8.

SECTION 7.

Station on Central Valley or Bar Cadete.

1st Break of Grade, 1100 m., losing 22 m.

2nd Break of Grade, 1250 m. of 1.28 per cent, losing 9 m.

JALAPA

SECTION 6. SECTION 7.

PLATE LXXXV
TRANS. AM. SOC. CIV. ENGRS.
VOL. XV, No. 344.
WELLINGTON ON
RAILWAY LINE IN MEXICO

NOTE TO PLATE LXXXV

[The fine horizontal lines are 2 metres (6.56 ft) apart on this profile. The total width of the plate is 8 miles, 111 metres. Its ties shaded. Retaining walls indicated by heavy lines and letters R. W. Many of the minor culverts have been omitted from the reproduction, but the culverts, drainage are on the entire line was in general very small.]

Notes of the Entire Mountain Grade and the Portions shown and not shown on this Profile

	Altitudes. Metres	Feet	Distances. Kilos	Miles.
Summit at Las Vegas	2415	7,923	0	0
Jalapa	1,265	4,150	5.43	3.364
Foot of 2 per cent				
Grade at RINCONADA	183	600.4	11.63	7.264
TOTALS, Whole Grade	2,232	7,323	114.8	72.64
Of which there is				
Shown on this Profile	1,050	3,440	54.3	33.64
Not shown " "	1,182	3,880	60.4	38.00

Lost by breaks of Grade on the entire distance 106 metres (4 tenths of a foot) of which there was ...
On the portion shown 36 metres (3.43 per cent)
" " " " not " 70 " (5.60 " ")

All of which and something more, it was expected to use up for compensation for curvature

PLATE LXXXVI.
TRANS. AM. SOC. CIV. ENG'RS.
VOL. XV No. 344.
WELLINGTON ON
RAILWAY LINE IN MEXICO.

MEXICAN CENTRAL RAILWAY—
Branch to the Pacific.
SPIRAL OF THE BARRANCA BLANCA
BETWEEN SAN BLAS AND TEPIC.

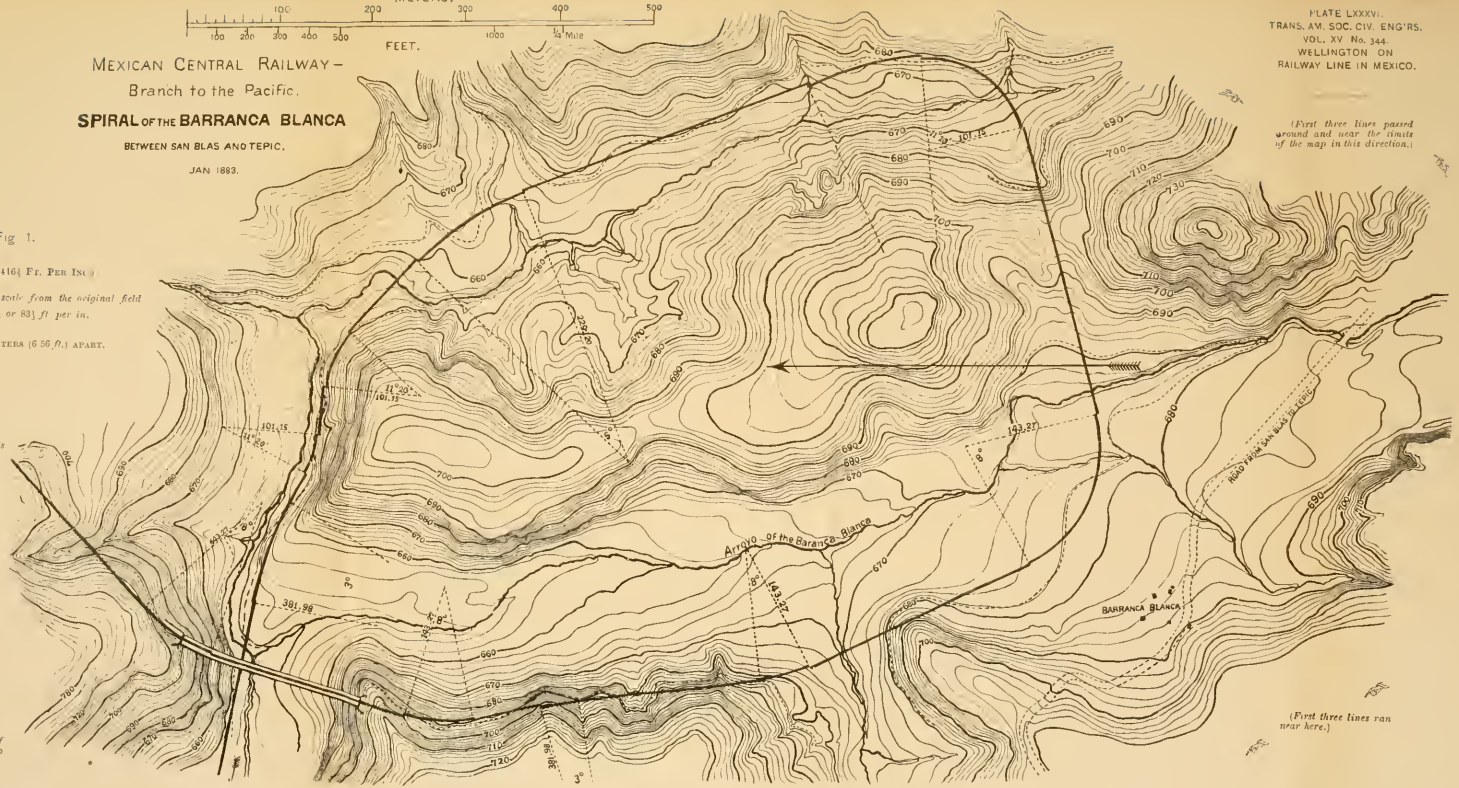
JAN 1883.

Fig 1.

SCALE [illegible] 416⅔ FT. PER INCH

Reduced one fifth scale from the original field sheets on a scale of $\frac{1}{1000}$ or 83⅓ ft per in.

CONTOURS, 2 METERS (6.56 *ft.*) APART.



(First three lines passed around and near the limits of the map in this direction.)

(Line from here ascends the small stream above.)

(Valley continues of this general character to B, fig. 2.)

(First three lines ran near here.)

Fig 2.

Alignment of the Grade descending to the Coast Flats from Tepic.

Showing the location of the Spiral and of the Various Routes previously surveyed.

(Black figures give elevation in meters.)

Notes to Plate LXXXVI.

The spiral illustrated is on the lower end of the Pacific Branch of the Mexican Central Railway, on the descent from the city of Tepic to the coast flats, work on which has been recently suspended before construction had reached the spiral. It was located by the writer, who was the late Assistant General Manager in charge of location, the late Mr. Edward Yorke, M. Am. Soc. C. E., Chief Engineer of the Pacific Branch, being in immediate charge of the surveys of the branch. Several efforts were made by various engineers to obtain a practical line, which are distinguished as first, second and third lines in Fig. 2 of Plate LXXXVI, but without any very satisfactory result, until, aided by the knowledge gained in the previous surveys, the idea of the spiral line was conceived and pushed to a successful completion, with a reduction of considerably over half in the estimated quantities of the line.

The spiral line, as finally completed, furnished an instructive example of the extent to which natural difficulties may be avoided by first selecting a place where a portion of the line can lie to good advantage, wherever it may be, and adapting the remainder of the line to it. The conditions, briefly stated, were these:

The town of Tepic is at an elevation of 915 meters, or 3 035 feet, above the sea, and distant only some 17½ miles east therefrom, half of which is a dead flat rising but a few feet above the sea, so that the entire rise would have had to be made on a direct route, within an air-line distance of some nine miles. Descending from Tepic (see Fig. 2), the line first follows the valley of the Tepic River until it diverges therefrom (as it flows in an entirely wrong direction and becomes impracticably rough) and strikes across into the valley of the smaller Ingenio River at the Rincon Pass, marked "controlling summit" on Fig. 2, at an elevation of 2 508 feet (795 meters) above the sea.

Up to this point the descent was on less than a 2 per cent. grade and offered no difficulty, although requiring some heavy work and affording views of great sublimity and beauty over the rugged and abrupt descent to the coast flats.

In descending from this controlling pass into the valley of the Ingenio River (which is the long stream in Fig. 2 which the line follows below the spiral), the usual difficulty was encountered, that the first descent was exceedingly sharp. In an air-line distance of two miles, from the controlling summit to the lower left-hand corner of the spiral in Fig. 1, there was a descent of some 490 feet. Moreover, the valley of the Ingenio, while entirely practicable for a line in or very near to the bed of the stream, had, for many miles below the spiral (to near *B*, Fig. 2) abrupt and rugged banks several hundred feet high, of the same impracticable character as those shown immediately below the spiral bridge, Fig. 1, although below *B* the valley became more tractable.

Under these circumstances, since it was impossible to descend into the bottom of the valley on any practicable grade, and since, unless this were done, the line must be, for a long distance below the spiral afterward adopted, entirely above the immediate slopes of the valley; to avoid the most excessive work, a comparatively light trial grade, 2 per cent., was not unwisely adopted for running the three first lines shown by dotted lines on the map. These lines, otherwise differing from each other greatly, agreed in swinging around the area covered by the spiral and close to the latter, although off the area covered by the map in Fig. 1. To trace them on the map of the spiral, start from near the scale and title and pass thence to the right, then down, and then, at the bottom of the map, to the left, to a point between *A* and *B* on the small scale map, Fig. 2. At this point they were already far above the grade of the spiral bridge, so that they soon left the excessive slopes of the valley and struck comparatively easy work on the narrow ridge lying between the valleys of the two parallel streams shown.

Nevertheless, the work on all three of the lines was excessive, while the low grade required a great amount of otherwise unnecessary development and curvature. Two of these lines were located on paper and profiles made, but no accurate estimates were ever made of them, as the work was very forbidding, involving, in spite of the use of 17-degree curves, a number of tunnels and many retaining walls and small viaducts.

These facts made it clear, if it had not been before, that the attempt to find a line by starting from the summit as a controlling point, and letting it fall thence where it would, must be abandoned, and a line lying in the bottom of the valley as a fixture and worked from at each end; that being the only place where a really economical line could lie for the entire distance down to *C*, Fig. 2, and in a measure down to *D*. The result goes far to prove the utility and necessity of this plan of locating really difficult descents which are measured by thousands instead of hundreds of feet.

A random line in the bed of the stream showed that a 2.6 per cent. grade (137 feet per mile) was the lowest adapted to it, and in assuming the line to be in this position, and extended from each end (*i.e.*, conceiving the line fixed under the bridge in Fig. 1), the ascent thence up the upper small stream was (for the country) mere surface work, and the extraordinarily favorable point for the high crossing (the narrowest for miles) naturally suggested sweeping the line around, through a deep, but narrow, cut into the lower small valley, so as to cross over itself by a high viaduct, and thence ascend to the summit. Above the viaduct it follows up the right slope of the small stream shown just under the title, being on the opposite side from the three previous lines, which chanced also to be somewhat the best side.

It was found on extending the line up to the summit that it left some

spare elevation, and this was properly concentrated within the spiral, in order to make the bridge as low as possible, although doing this had its painful side to the engineer, as the topography readily admitted of an unbroken grade within the spiral and some 50 feet more rise, with even lighter work both within and above the spiral, except that the viaduct would have been higher. Its length and cost would have been very slightly increased, but enough to make it inexpedient.

There was a possibility of a direct line from Tepic to the head of the spiral, following approximately the highway *via* La Fortuna, but it was not deemed worth survey, for these reasons:

First.—It was certain that it could afford no better grade, and but little, if any, difference in curvature, distance, and cost.

Second.—The fine water-power of the Rio de Tepic would have been left at one side, with the mills already on it, and the others which were very likely to be placed there—water-power being very scarce in Mexico.

Third.—There was considerable local traffic from La Escondida and points beyond it to the West, which would be lost.

Fourth.—A dull, uninteresting ride would have been substituted for one of the greatest scenic attractions. A chief dependence for the traffic of the Pacific Branch (and for the main line of the Mexican Central as well) being tourist traffic, and much of the remainder of the line being of great scenic beauty, this alone was deemed a decisive consideration.

The leading dimensions of the spiral and viaduct are as follows:

Length of spiral, 2 637 meters..... = 8 652 feet = 1.64 miles.
(405 + 60 = 669 + 30, with 10-meters station).
Descent in spiral, actual.....53.00 meters = 173.9 feet.
Descent in spiral, on 2.6 grade.....68.56 "

Loss of elongation in do.....15.56 meters.

Utilized as follows:

For curve compensation, 303 degrees (at 0.06 per degree)..... 5.56 meters.
Spare elevation, utilized for a station ground and water station at south end of spiral..10.00 "
Viaduct: Length, 200 meters ..... = 656 feet.
Height, 53 " ..... = 173.9 "

The height is above the grade line. Above low water it was some 7 feet more.

The material to be handled was not rock, as might be inferred from the excessive slopes (which are rarely as flat as 1½ to 1), but in part *tepetate*, a kind of volcanic tufa of the hardness and color of very soft-baked clay, found in vast masses in all parts of Mexico, so that it constitutes on many long stretches of railroad nearly all the material moved below a thin soil, and in part *jal*, which consists of thick sand-like deposits of little particles of pumice-stone of the size of a pea or bean, as white as snow; whence the locality derived its name of *barranca blanca*, or white gulch. *Jal* (pronounced *haal*, with strong aspirate), though perhaps the lightest of known materials, holds, like *tepetate*, a very steep slope when protected from wash. Neither *jal* nor *tepetate* exist in any part of the United States or (so far as known) Europe, so that there is no English name for them.

Jal is so abundant in that part of Mexico, that the name of the state, *Jal-isco* (the largest state of the republic) is derived from it, and it is certainly in one respect the most extraordinary of known materials. If the whole country were to be gently sunk below the sea, the upper 20 to 200 feet of vast areas of the soil of that state, aggregating thousands of square miles, would rise and float upon the water, carrying in many cases trees, houses and cultivated plantations with it.

The dotted grade-line on Fig. 1 will enable the character of the work to be seen at once. The contours are two meters (6½ feet) apart, and along the line are minutely accurate. Owing to the excessively steep slopes on or near to the line, it was located with a view to doing most of the grading by large earth (*tepetate*) blasts, which will explain the way in which the line is laid at certain points. Rock crops out above and below the spiral to a considerable extent, being in all cases basaltic lava, with which the whole country is underlaid, but not on the spiral itself, so that its cost was even less per mile (exclusive of the bridge) than the average of the line. The bridge itself was estimated to cost in the neighborhood of $50 000, which perhaps was too low.

The cost per mile of various sections of the road was estimated to be as follows, at about the usual American prices; the sums given include earth and rock grading and masonry only. There were no tunnels, but some eight or ten small iron bridges or viaducts.

No. of Kilos.	Locality.	Cost per Mile.
10.	From controlling summit to and past the spiral	$14 630
	Above Spiral.	
8.	First below Tepic	16 680
5.	From Escondida to Rincon Pass	58 900

Below Spiral.

11.	First below spiral	14 700
10.	To near *B*, Fig 2	13 120
4.	Near *B*, past *C*	30 800
7.	*C* past *D* to limit of map	21 800

At the limits of the map, Fig. 2, the line is still some 20 miles from the coast, but only some 75 feet above it, and the difficulties are over. It will be seen that the section, including the spiral and line in the vicinity, is among the cheapest on the descent, where before it had run for many miles over $120 000 per mile for grading and masonry only. The most costly work was on the three miles passing from one valley to another. The limit of curvature was 17 degrees (foot system--11 degrees 20 minutes metric, for 20-meter chains).

DISCUSSION.

Robert Moore, M. Am. Soc. C. E.—There are one or two questions I should like to ask Mr. Wellington. The conclusions of his paper were certainly very surprising, and did not seem to follow very obviously from the premises. The first question in regard to the author's solution of the problem of overcoming great heights is how anything is saved in distance; in fact, why there is not a loss in distance by those continuations of the line beyond the point of curve. And why there is not a very material loss in the operation of the road by the necessity which that involves of running the train half the time backwards uphill, which, as every one knows, is a very trying method of operating a train. Still further, I would like to know what he would consider the limit of traffic for which he would construct such a road. As I understand him, it is suited only for roads of light traffic. If, therefore, he should construct a road for a traffic of a certain number of trains or tons, and the history of the road should develop a tonnage or train mileage five or ten times that, as very often happens, what would be the condition of the road? Would it not have a location extremely faulty, one which would need to be wholly remodeled, the old alignment being thrown away? I should say generally that I do not know of any more uncertain business than that of estimating upon the future traffic of a railroad, and it seems to me that any system of location which makes a correct estimate of the magnitude of the future business of a road an essential feature in establishing the alignment, rests upon a very uncertain basis. Most of our railroads, even those which are now most heavily taxed, were expected to have a very light business. Time has developed that they have a very heavy one. I think, therefore, that it is safer to locate for a heavy business than it is to locate for a light one, and that a method of location which is based necessarily and essentially upon a light business is a very unsafe one upon which to proceed.

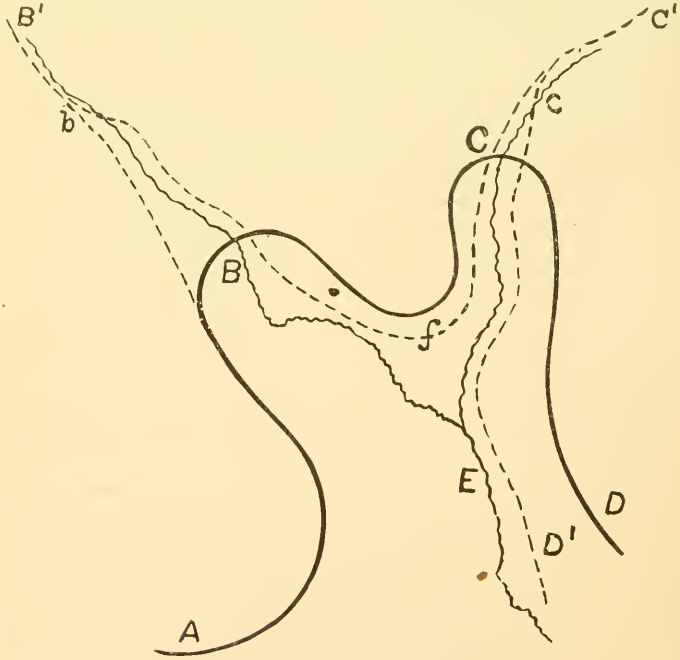
A. M. Wellington, M. Am. Soc. C. E.—I am very glad to have the gentleman raise those points, because they are ones that need of course to be considered. I will touch upon the last one first. I have studied the financial history of railroads a great deal. I could very readily name a great number of roads—I will just mention one that occurs to me now, the West Shore—that have been ruined by starting out with the assumption that they were going to have a magnificent traffic from the first, and that they must have everything strictly first-class for twenty or fifty or more trains a day; but I have yet to hear of the first road that has been ruined by having so much traffic to accommodate that it could not carry it on its own line as originally laid out. Therefore I think that before touching on a question of what limit of traffic can be done over

such a system as I have suggested, the first question is: Is it adapted for a comparatively light traffic, such as all the railways in Colorado and Mexico, and in the Rocky Mountain region generally have to-day, as they had twenty years ago, and as they will continue to have, beyond question, for ten or twenty years to come? It is an almost invariable rule that roads through severely mountainous countries, lines that must be carried over 1 200 or 1 500 feet of rise or more, will continue indefinitely to have a comparatively light traffic. A striking example that occurs to me are the roads in Peru.

The location which is the subject of this paper was made without switch-backs, in conformity to a sort of accepted standard among engineers, that if a location is to be regarded as really good it must be carried on a continuous descent from the summit down, no matter at what cost. The fact that, in Peru, it became necessary to put in switch-backs, is generally regarded as distinctly reducing the credit of the location. Hence, even if I had believed in using the switch-backs as much as I do now, I should have hesitated to use them on my Mexican line, for I should have felt that it would have detracted from the apparent merit of the line, and, both as an engineer and as one acting for a company, I should have felt that I was doing the road an injury. But I think that the contingency suggested by Mr. Moore, of great, but dubious, growth of traffic in the distant future, in such localities where the cost of first construction is very great, is one that is entitled to little weight in the initiation of lines which are very costly at best. The only proper assumption on such roads is that the traffic is going to be light, and that paying the interest on the bonds is going to be difficult, and paying a dividend to the stockholders almost impossible. That is the actual history of at least nine out of ten of such lines, and it is not good financial judgment to consider more than the traffic "in sight," or for eight or ten years ahead. Nevertheless, while the contingency of how large a traffic might be accommodated on such a system is not likely to become important on most mountain lines, I see no reason why a very large traffic cannot be accommodated, fully up to the limit that can be accommodated by a single track elsewhere.

In regard to the question raised by Mr. Moore, as to whether there is not a great loss of time and distance, I reply that the system recommended results in no loss of time, and that there is even a saving of distance. If the gentlemen will look at that section of the switch-back shown in Fig. 3, page 821, they will see that the train as it comes up from the lower grade runs up on the sharper grade at the end of the switch-back and returns backwards. Every foot of that distance on the Y counts as so much effective distance both ways, because the engine uses steam on it both ways, so that the distance on the Y counts twice. The reason may be more fully explained thus: A locomotive is capable of burning a certain amount of coal and no more. A certain amount of

coal represents a certain number of foot-pounds, and a locomotive can generate in an hour or a mile a certain number of foot-pounds and only that. Now, when the locomotive is ascending a certain height with a train, the weight of the train, multiplied by the altitude to be ascended, is the amount of foot-pounds it must do. It can generate a certain number of foot-pounds in an hour. Unless it loses a certain amount of time when it is not generating foot-pounds, it loses no efficiency from the fact of going up a short stretch of track and back again. The fact that there is also a stop is something that must likewise be discarded from the mind, because, by the arrangement of the grades it involves no loss of power like an ordinary stop. If the engine is putting the steam through the cylinders, it is doing just as effective work in lifting the train up the hill on this short stretch as if it were running forward. It is not necessary to shut off the steam to stop the train. The grade does it. It is only necessary to throw over the reverse lever as the engine comes to a stop. Of course, when descending, the power developed not being used up by the resistance of the grade, is stored in the train in the form of velocity. That velocity helps it to go up the next grade, so that there is no reduction of efficiency whatever. On the contrary, there is a



Sketch 1.

somewhat shorter total length of rails to be gone over. The conditions are entirely different from those which obtain in an ordinary stop, which involves very serious additions to the virtual grade.

In regard to the final question of Mr. Moore about "running half the time backward;" running "half" the time backward would be a very serious objection indeed; but it is not a necessity, and is not contemplated in the plan that I have suggested. It would only be a very short distance that the engine would run backwards if the line were properly laid out. An example is shown in the accompanying sketch, No. 1. A line descending from *A*, and having to pass the two gulches of the stream *E*, will probably have very costly crossings at *B* and *C*, with sharp curves and probably tunnels in between, and yet find itself high above the stream at *D*. Some one or two such difficult points are very often prohibitory to an otherwise excellent location, or include within a short distance a large part of the total cost of the ascent. At one or two such difficult and governing points of a long ascent, the switch-back enables us to adopt the plan of location $A\ B^1\ C^1\ D^1$. By it we save (1) 360 degrees to probably 400 degrees or more of curvature; (2) the cost of the high crossings *B*, *C*; (3) the additional cost in the vicinity of the crossings, tunnels, deep cuts, etc., which the necessity of making the semicircular curves usually involves; (4) the distances $B^1\ b$ and $C^1\ c$, which count twice for climbing the hill for one length of rails; (5) the difference of level $D\ D^1$, gained by running down into the very bottom of the gulches above; (6) cheaper construction below *E*, due to the lower level of the line; (7) a substantial addition to safety, since a runaway train or car will be stopped by the Y's, if it does not come from too far above. Against this there is only to be charged the disadvantage of running backward over the short stretch $B^1\ C^1$, which can be made a slight one either by using locomotives of types best adapted for running backward, or by spending a fraction of the sum elsewhere saved in obtaining an easier curve at *f*, the sketch being one from an actual instance in the writer's practice, but drawn from memory, the line *A B C D* having been that constructed. To sum up, you save lives, cost of construction and elevation. What you lose I do not know.

William Watson, Assoc. Am. Soc. C. E.—Could you give, approximately and very roughly, the amount of traffic that passes from Vera Cruz to Mexico?

Mr. Wellington.—From Vera Cruz to Mexico there pass two passenger trains a day on the plateau, one passenger train each way on the heavy grade, and six to eight freight trains. The business of all the roads in Colorado is insignificant. The New York Central road does more business in a week than any piece of road in Colorado does in a year, and it must continue so for a long time to come, because in such regions the universal law is that rates are high. The necessity of some kind of road is

great, because the mining regions must have supplies; but the absolute quantity of the traffic must be very small.

Prof. WATSON.—If the road had been constructed with switch-backs, would the traffic have been under no such limitations? Do you think that your assumptions would have been true on the road from Vera Cruz to Mexico?

Mr. WELLINGTON.—As to the traffic that can be accommodated on a single line, the best illustration is the Fort Wayne and Chicago, I think. That runs the largest traffic of any road in the country on a single track. I cannot say what the traffic is, but they have run in busy times fifty trains a day, and much more on single days. You can divide fifty trains a day into twenty-four times sixty minutes and you will see how often they must go.

Mr. MOORE—In regard to the comparative immunity from accident claimed by Mr. Wellington for this system of switch-backs, it occurs to me that the chances of casualty entailed by the numerous frogs and automatic switches, every one of which is a source of possible derailment for every train, much more than counterbalance the supposed additional safety in the case of loose trains. And in regard to these, there will be danger of running off the ends of the Y's, or of sharp or possibly fatal collision with a bumping-post, unless the grades and lengths of the switch-backs be adjusted to the greatest speed which can ever be attained by a loose train, and be in consequence quite out of adjustment for the ordinary business of the road.

And as for the particular case which has been referred to, of the Marshall Pass, the work, as I remember it, is nearly all light, and I think that to construct switch-backs into the mountain side at the upper ends of the ravines which he indicates would entail work much heavier than the present line. And this I think would often be the result.

I should say, however, that Mr. Wellington's chief error is one of over-statement. For particular cases no one can deny the great value of the method of location which he proposes, nor the great skill with which he has worked it out; but when he recommends it for general adoption on heavy inclines in preference to the ordinary method of a continuous grade line, he is, I think, stating his case much too strongly.

And I must confess that I do not quite see how, when his train is standing still, and when no steam is being used, there is not a loss of either time or energy, or both.

Mr. WELLINGTON.—The Marshall Pass was mentioned by me only in an illustrative, informal way before I had seen the ground. Now that I have seen it, the character of the topography there is wonderfully favorable for a continuous grade line, the most so of any high summit line I ever saw; but at the Georgetown spiral we have a good example of a point where switch-backs would have been greatly advantageous in

every way. The alleged danger of running off the end of a switch-back may be cured, as in many existing switch-backs, by a short stretch on a continually increasing sharp up-grade, not comfortable for regular use, but sufficient to prevent accident to runaways. As to loss of energy from the stop, if the gentleman will permit me, may I ask if he has ever seen a pendulum swing?

Mr. Moore.—I believe I have; yes.

Mr. Wellington.—Can you inform me how much loss of energy there is from the stopping of the pendulum?

Mr. Moore.—Is there any exertion of energy when the train is standing still?

Mr. Wellington.—Up to the very moment that the train starts the engine is working full. It is stopped, not by shutting off the steam, it is stopped by what would not be noticed by a person walking over the track, the rise above the regular grade line. How much rise, at a certain speed, is necessary to destroy the entire velocity of the train and bring it to a stop, can be figured down to the thousandth part of a foot. It is also certain if the energy is absorbed by lifting the train, and the train is afterwards allowed to descend, that there is no loss of energy whatever. Energy can be taken up and stored just as well as it can be used at once. It is not necessary, up to a certain limit, to use energy at the moment that it is exerted to save its loss. It can be stored in the train in the form of velocity, or it can be stored in the train in lifting it up to a higher elevation, as it is when brought to a stop. In regard to the question of the danger of switches, why many of us here in Denver have come by the limited express from New York, and we have run over thousands of switches, and it is done continually all over the country. How many accidents do we hear of from that? Not nearly so many as we do from the breaking in two of a train. The breaking in two of trains is one of the great dangers on grades and it results in some of our most terrible accidents; whereas our train in ascending is ascending at slow speed. It goes through a switch properly laid out with perfect ease, and it is only gross carelessness in setting switches wrong that causes almost all the accidents of that sort that we have. The breaking in two of trains on grades is a constant danger. It is proposed, moreover, to eliminate human fallibility by having the switches operated automatically.

In regard to the queston of how much is saved by using a switch-back, it is a new idea to me that it can be cheaper ordinarily, under any circumstances, to put in a curve, which must have a pretty large radius and must therefore be carried with a cut on each side and a high viaduct over the stream, than to run right up into the bed of the stream.

The gentleman said that I laid this down as a general law of location. I beg to correct him. I laid it down as a general law of location for

carrying a light traffic over high inclines, under which I class anything over 1 200 or 1 500 feet. There are many places where it might be used at lower elevations of 800 or 1 500 feet, but I did not lay it down as a general law for anything less than 1 500 feet, with light traffic. But there are great numbers of such points all through the country, and there will be more.

J. B. Johnson, M. Am. Soc. C. E.—The gentleman has spoken with so much confidence that there was actually no loss of economy, that I think it well to call his attention to the fact that there is a loss, of course, equal to the movement of the train over the portion which is traveled twice, and it is the loss which is entailed in drawing the train over that distance twice on level ground. That is not very much, but that part of it certainly is lost over the power necessary to ascend the same elevation on a continuous two per cent. grade.

Mr. Wellington.—I must beg to differ from the gentleman. I fail to see how there is any loss whatever. A locomotive, to exert a certain number of foot-pounds, must run a certain number of feet to make the ascent in order to generate that energy. If it generate it by running over a short bit of the line and running back again, so much the better. On the contrary, there is a very slight gain—the resistance decreases from the checking of the speed. It is increased, however, by the sudden increase of the speed; so it is about even.

Mr. Moore.—How about the loss of time? Could you operate a passenger train over this as speedily as you could otherwise?

Mr. Wellington.—Rather more so, for this reason, that you come up with a certain velocity, ten or fifteen miles an hour. You stop for an instant at the end of the switch-back. Then you descend and your descent gives a velocity due to the altitude 3.2 feet (see Fig. 3, page 821), and likewise the amount of separation of the two grades, which is 32 feet, which is 35.2 feet. That velocity represents about thirty-one miles an hour. Starting up the grade at that velocity, which decreases up above to whatever is your minimum speed, makes the average time a little less. At the same time you cannot make much difference in that way, because it is to a great extent a question of how much power the locomotive can generate in a given time as well as a given distance. If you attempt to take the train up any quicker you must cut down the train in proportion.

Prof. Johnson.—With a two per cent. grade from a given starting point to a given point at the top, it takes a given distance, a given length of road, to pass from one point to the other. That was the example that was given us. Now, if the switch-back is also a uniform two per cent. grade, then it would certainly take a longer piece of road to reach from the given point at the bottom to the given point at the top, and it will be longer by just the amount of track that is passed over twice; and it was on that

kind of a conception of the problem that I stated there would be a loss of energy equivalent to traveling that additional distance twice. Of course the gentleman is perfectly right in what he says as to a gain in time for generating steam, and it all depends upon the point of view from which we make our estimate of loss or gain. In the sense that you have to travel a longer distance, there is the loss which comes from that additional distance; that is, in passing from the bottom to the top in the two cases there are more foot-pounds of energy used with a switch-back than with a uniform grade, by the amount already specified. This is, however, a matter of small consequence.

Mr. Wellington.—The only difference is the fact that the train starting from that high position gets a sudden start, and has that initial energy to assist it; so that, although there is a loss of distance in one sense, yet if you had those switch-backs every three or four miles you would have a less virtual grade than two per cent., and could increase the actual grade for a short switch in proportion.

Mr. Moore.—Would you lay out the vertical curves at the ends of your switch-backs for your fast trains or for your slow ones?

Mr. Wellington.—I would lay them out for both, the first part for slow trains, the extreme end for fast.

Mr. Moore.—What I mean to suggest is that the proper adjustment for a fast train would not be the proper adjustment for a slow train.

Mr. Wellington.—Yes; only the fast train would run a little further out. The effect would be the same. Then a fast train always has a certain excess of power necessarily, so that it would check speed and not run so far off. The great reason why I should say that this plan would be advantageous, would be, (1) that it reduces the first cost very largely in a direct way; and (2) it enables locations to be built on that otherwise could not be built on at all. I have not yet been over the railways of Colorado, but I have no doubt that there are many illustrations in Colorado where they could have kept on very nice smooth ground if they could have used two or three pair of these switch-backs, on which they would have had to run backwards no more than a mile or two in the whole ascent.

A Member.—What is the length of rail used? Would there not be more tons of rail?

Mr. Wellington.—No, we use less, by just exactly the length of that switch-back, because we run up and run back, and that run in both directions counts as so much work done. The engine is using steam in ascending and descending. This question of the modifying effect of stored energy in grades is a subject not discussed in engineering books, which is greatly to be regretted, because it leads to very imperfect treatment of grades. In this case the train is lifted up to bring it to a stop, and that is a permanent gain, because in descending, although it

descends, it acquires a velocity which will lift it back to where it started from without aid from the engine, leaving that work as so much over.

H. H. Filley, M. Am. Soc. C. E.—I believe it is nearly universal now to compensate for curves, and it is easy to conceive that by throwing out 360 degrees of curvature as much is gained as lost on the switch-back. As much elevation is gained as is lost with the extra length of rail on the switch-back.

Mr. Wellington.—I do not lose anything.

The Chairman, Robert B. Stanton, M. Am. Soc. C. E.—May I ask, do you mean in connection with that two per cent. grade that it is a continuous two per cent. grade on your switch-backs from the bottom to the top, taking your point of switch as your turning point on to your other line?

Mr. Wellington.—It would depend altogether on the location of these switch-backs. In the particular instance I have sketched there is a very short distance between switch-backs, say a mile. In that case you have a velocity equivalent to about twenty vertical feet of "head;" you can increase the two per cent. grade by that twenty vertical feet, and still have in that distance a virtual two per cent. grade. It makes no difference what the actual grade of the track is, the train will be floated over it by its stored energy, as if it were going over an actual two per cent. grade without the aid of that energy.

Mr. H. P. Taussig.—The gentleman says the grade is increased. If your limit is two per cent. you are increasing the energy required. I admit that you get the benefit of the increased energy going back off the head block and up the rise beyond. I mean starting from the bottom of the hill up. An engine starting at the foot of a grade will go up that grade a considerable distance, but it generally comes to a stop unless we have a pressure behind it, and in this same case you are increasing your grade right to the very top of your hill, and I do not see how in the world you are going to get over that ground.

Mr. Wellington.—I seem to be doing a great deal of talking, but this is a very important point, and as I say, one not dwelt upon at all in books on engineering. The case stands thus: Starting from the foot of the hill you have a two per cent. ruling grade, which is supposed to be the *de facto* ruling grade. You increase it for a short stretch at the end of the switch-back for the very purpose of bringing your train to a stop, and it does so. But, unlike an ordinary stop, you are then at liberty and required to run backward down the same grade about a train length, which at once gives back your original velocity and a little over, due to the work of the engine. How much over can be precisely determined by the laws of acceleration of velocity, and you are at liberty to increase the grade beyond by just that much and no more. This increase makes no change whatever in the virtual grade, but leaves it two per cent.

Mr. TAUSSIG.—I understand your pendulum doctrine perfectly, but I do not think it works with steam.

Mr. WELLINGTON.—It is not applied to "steam," but to the energy already created from steam. All energy is the same. A certain velocity means a certain amount of energy, and the two are interconvertible indefinitely under proper conditions.

M. COHEN, M. Am. Soc. C. E.—Having had some practical experience in the construction and working of a switch-back railway, I may properly say a word or two on that subject. During the construction of the Baltimore and Ohio Railroad there was occasion at two points to use a temporary road over the top of the tunneled hill during the construction of the tunnel. In one of these cases the ground was difficult and the crossing was made by two switch-backs, or Y's as we termed them, on one side of the hill and five on the other. The maximum grade was six per cent. This was reduced to four per cent. on the alternate stretches, that the locomotives, which were run with head up hill on the heavier grade, should be less liable to lose the water from their very long fire-boxes when running up grade with fire-box in advance.

In this construction the rule was to make the stem of the Y level, but the topography was such that in two of the Y's, with a limiting radius of 300 feet, the line ran off the bank, and, in order to find support for a sufficient length of stem, trestles were resorted to. Here, instead of making the stem level, we were glad to avail of gravity to assist in bringing the train to rest, and the grade was continued to the very end of the Y.

In working that track it would never have suited to start back from the Y at a high rate of speed. The great danger was at the point of the frog, where the adjustment was always difficult owing to the reversed grades and very limited choice of ground. The practice was to come out upon the Y all cautiously and carefully, come to a stand, reverse, and, being sure that the switch was turned, start back with equal care in the opposite direction. We dared not there avail of the arrangement which Mr. Wellington proposes, to use gravity to start the train rapidly from the Y.

With regard to the possibility of working such a track effectively, the completion of the tunnel having been much delayed, the whole traffic of the Baltimore and Ohio Railroad was run over those seven Y's during the winter and spring of 1853, and very successfully. There were no accidents that I remember, except, I think, to a car of road hands who were letting themselves down by the brakes. They carelessly allowed the car to get beyond their control, dashed out on the trestled stem of one of the Y's, and, notwithstanding its upward inclination, were pitched over the end of it and brought up in the ravine below.

C. M. WOODWARD, Assoc. Am. Soc. C. E.—At the risk of coming

back once too often to the same discussion, I would like to say a word upon this matter of loss of energy and length of road. It seems clear to me, and I presume to almost all, that a road would be longer by just the amount of the switch-backs, and that the journey of the locomotive from the bottom to the top is longer on a switch-back track than on one with a continuous two per cent. grade by just the lengths of all the switch-backs.

Now, the amount of steam used, if the steam is used continuously under conditions otherwise equal, depends upon the number of revolutions that the wheels make. The cylinder is filled with steam twice for every rotation of the driver. If therefore the journey of a locomotive is longer on a switch-back track than on a regular track by the length of all the switches, as it clearly is, then the number of revolutions will be greater in exactly the same proportion, and if the steam is not shut off, the amount of steam used would be greater inevitably by just that same proportion. The loss has been spoken of already by some others as that due to the friction of wear up and down a certain length of track. There is no loss, as Mr. Wellington very properly says, supposing it could go up and back again without friction, it would be simply stored energy. Of course, heavier loads could be drawn, but not in proportion to the extra steam used. So far as the cost of the road is concerned, there might be an argument on the other side. Perhaps there would be less sharp curves on the line.

Mr. Wellington.—It seems to me that Professor Woodward, instead of opposing anything that I have advanced, is distinctly supporting it. I distinctly took the position that you did gain distance. You make so many revolutions of the drivers, which means so much energy. Now, if you had those switch-backs at certain distances apart, and only two per cent. track in between, I grant that it is not a virtual two per cent. grade, it is about one and three-fourths. I grant, also, that if these come at unequal distances apart, with the same actual grades in between, you have a virtually unequal grade, higher at some points than others, and as the heaviest points govern, of course, there will be a loss—or, rather, no gain—at the other points. But with these inequalities rectified by laying out steeper actual grades for the short stretches, where there is surplus velocity, the more distance you take to get up with the engine the less grade you have, and the less grade you have the more you can haul up. Therefore it is a question of economy and engineering whether you will go a short distance and haul a short train, or go a longer distance and haul a longer train.

Mr. Moore.—There is one point which does not seem to have been brought out quite as clearly as it deserves, and that is, that granting all that Mr. Wellington claims, this method of operating a railroad requires for its success that everything shall be in perfect order, whilst the road

which he proposes, with its automatic switches and nicely adjusted grades, is a delicate machine, and peculiarly liable to disarrangement.

As an illustration of one of the difficulties that may arise in practical working, let us suppose an engine coming up the hill, and loaded with all it can take, at the speed necessary to carry it past the switch and to the end of the Y, finds it necessary to stop at or near the change of grade. The switch, or the track, or the engine, we will say, is out of order, and the train stops just at the point where the grade begins to increase. It will then be compelled to start up this steeper grade without the aid of the energy stored as velocity, which is necessary at this point, and will therefore be unable to go forward at all, as it could do on a continuous grade. Contingencies of this kind will often be likely to happen. You load your train, say, for a two per cent. grade, but at the switch-backs you meet a grade which is much steeper, and up which you cannot go unless you are going at a certain calculated speed. If for any one of many reasons you have a speed less than this you cannot get your train clear of the switch, and must stop. On a road with continuous grades, if you cannot go fast you may go slow. But on one such as Mr. Wellington proposes, if you cannot go fast you cannot go at all.

Again, as I understand Mr. Wellington's theory, he proposes to avoid the loss of energy which must otherwise occur, by taking his train up the hill without at any time shutting off steam. When his train stops on the switch-backs he does not touch the throttle, but instantly reverses his engine, and continues working full steam, at first down a sharp grade, and half the time backwards. But to do all this safely requires not only that the reversing lever be thrown over at the exact moment, which with cylinders full of steam is by no means the easiest thing in the world to do, but requires also that everything—the train, the track, the automatic switches—shall be in perfect order. If this be not the case, both time and energy will be lost.

Amongst the "thousands of switches" mentioned by Mr. Wellington as passed over in safety by the Eastern Members on their way to this Convention from New York, there was, I may safely say, not a single one of the kind which he proposes to use. Not one was automatic, but every one was securely locked in position, and moved only by a switchman.

Nor is the exact adjustment of the grades on the switch-backs to all the varying conditions of traffic, by any means a simple problem. An arrangement of the line and grades which might be just suited to a train of loaded cars would not be correct for a train of empty cars, as in the latter case the distance from the switch to the end of the Y ought to be two or three times as great as in the former. In like manner, if the switch-backs be adjusted for trains going up hill at a speed, say, of ten miles per hour, they will not be correct for trains coming down hill at a speed two or three times as great; or, if adjusted for the down trains,

they will be longer than is necessary for the up trains, and every unnecessary foot means not only a loss of money in first cost, but a loss of time forever afterwards. So that, on the whole, I am inclined to share the feeling to which Mr. Wellington alludes as prevalent amongst railroad engineers and managers, that switch-backs, even such as he proposes, are to be resorted to only where they cannot be avoided, and that they do "distinctly reduce the credit of the location."

Mr. Wellington.—A switch-back system such as I propose has never been used at all, except on a very small scale (at Mauch Chunk), where it worked perfectly for years. Without proper adjustment of grades to them and proper handling of the switches, automatically or otherwise, switch-backs are, I grant, a great nuisance. As to the "thousands of switches" passed over by the Eastern Members, or, I will add, by the gentleman himself, from St. Louis, I am astonished that he should make such an assertion as that he might "safely say" there was not "a single one" of the kind which I propose to use, or that "not one was automatic, but every one was securely locked, and moved only by a switchman." At the gentleman's own city, as in all other large yards where safety and efficiency have become important, interlocking apparatus is alone used, which is "automatic" in exactly the sense that I propose, and it is like going back to the dark ages to hear any one claim or imply that switches "moved only by a switchman" are the safest or best. On the contrary, they are a recognized source of constant danger.

Finally, as to the question of trains sticking on the grade, I am glad the gentleman raised that point, because he has suggested to me something that I had not brought out. He well remarks that in operating the switch-back everything must work well, or you will have trouble. The same is true of any kind of railroad operation. A train is stuck on a continuous grade. It has to go back to the next place where there is an easing up of the grade, and sometimes it is miles away, so that it is very difficult to do that. Supposing now, an entirely improbable supposition, that a train which could be hauled elsewhere on the grade, could not go past the head block of the switch-back at ten miles an hour, what happens? If the conductor were a "live man"—and if he were not, he would soon learn the trick anyway—what he would do would simply be this: He would set the brakes on the rear end of the train, uncouple in the middle, run the front part of the train up on the switch-back, and back on the up track, and leave it there; go back and pick up the rear, put it on behind, and go off on his business; and if he could not get a good start he would see-saw in the hollow of the up track until he did get up the necessary velocity. That is one of the great advantages of that system of laying out a line, that if a train gets stalled, it can in emergency work itself right straight up the grade, and it is

really impossible for a train to get stalled with this system anywhere in the vicinity of the switch-backs.

Mr. F. D. H. Lawlor, Jun. Am. Soc. C. E.—It would be necessary to have a switchman for each one of these switches, and if we pay them $500 a year each, that at five per cent. would represent a capital amount of perhaps $20 000. Suppose we have four or five of those switch-backs, we get a capital amount of $80 000 or $100 000. Of course it is simply a question of which would be more economical—to put in a high trestle or deep cuts, or to make an investment in salary for these men. I think in a good many cases the reason our trains have to double is on account of the drivers slipping. Our engines are rated, say, to their full capacity, and it is not a question of the amount of steam they can use, but it is a question whether the load on the drivers is enough to prevent their slipping. Now, where we have a switchman to throw the switches and see that the switch is in good order, and a train comes up, and when it arrives at that switch the drivers are almost slipping, if the grade is increased right at that point the train will have to double. It would be all right, I think, to make the switch-back for that mountain on some grade that we have on the other parts of the road, but if we increase the grade we are slipping the drivers and the train would have to double.

Another gentleman made a remark about the point of the frog, where you go up on an up grade and then you drop back to the point of the frog and then change suddenly and go up again on your switch-back. I think that could be overcome by continuing the down grade beyond the frog for some distance and getting room to put in a vertical curve; descending a little from the point of frog would increase your velocity, of course.

Mr. Wellington.—I have so shown the grade in Fig. 3, page 821. Of course the length of the lead must be on one grade. You cannot run through the switch on one grade going up and on another grade coming back.

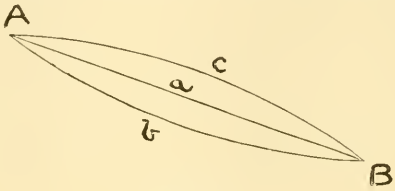
In regard to the capitalized value of switchmen, I have not proposed to use any switchmen, for this reason—that signal engineering has been perfected so much that there is no difficulty whatever in making that thing entirely automatic. Two or three of the interlocking switch companies would take an order to make that apparatus entirely automatic. I have asked an engineer, a Member of this Society and connected with the Pennsylvania Steel Company, about it, and he told me there would be no difficulty whatever. I was cognizant of the fact before, but I asked him to make certain.

In respect to slipping drivers by increase of grade, drivers only slip when the tractive resistance is increased. I have not proposed to do this, but to use the short bit of higher grade to absorb the energy of the train, and bring it to a stop without loss of energy. I am sorry to have to dwell so much on such elementary matters.

Mr. Filley.—I would like to ask Mr. Wellington if he proposes to make up the loss of time that it takes a train to run on to the end of the switch-back and stop, by the stored energy, and at the same time increase his grade just above the switch-back to make up for the rise that he has made on the end of the switch-back, both saving his time and increasing his grade at the same time.

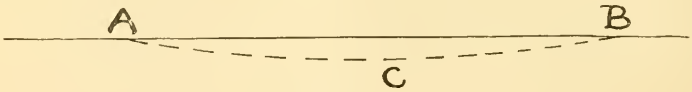
Mr. Wellington.—It is a little difficult to go into that point without taking more time than is proper.

But velocity, mechanically, is not a question of power. It is not a question of so much power and so much velocity. Every one knows



Sketch 2.

that you can take a body at *A* and let it descend (Sketch 2) to a level at *B* by either of the paths *a*, *b*, *c*, and while the velocity on arriving at *B* will be the same by either path, the time consumed in passing from *A* to *B* will be entirely different, although the amount of work done on the body, as well as its final velocity, will be exactly the same. As the train starts, going up the track beyond the switch-back with a pretty high velocity, it necessarily has a higher average velocity. That higher average velocity does not need any greater exertion of energy. It is simply a question of the path over which a body moves. It gets the body over a given distance with the same energy in a shorter time, just



Sketch 3.

as a train which would move along the straight grade *A B* (Sketch 3), with a uniform velocity of fifteen miles per hour, will, if there be a slight sag *C*, in the grade, pass over the distance *A B* in less time than *via* the straight grade, although passing both *A* and *B* at the same velocity.

Mr. Filley.—I can understand that by giving the train a start from the end of the switch-back it will make up the time it has lost, so that in the next mile, if the grade is kept at the regular maximum, your average speed will be higher; but to increase the grade in this next mile, it seems to me, is to commence losing velocity, and at the end of the mile you will have lost all that was stored up at the end of the switch-back.

Mr. WELLINGTON.—Mr. President, I regret to do so much talking, I assure you, but I am asked questions and have felt bound to defend myself. I will now simply add that average velocity is approximately the mean of the initial and terminal velocity. If you start at twenty-five miles and get to the top at fifteen, your average velocity is twenty miles an hour.

Mr. FILLEY.—Yes, and suppose you increase the grade so that you reduce your velocity within the next three hundred feet beyond the switch-back to your original fifteen miles an hour ?

Mr. WELLINGTON.—Mr. President, I could very easily, by taking time, and drawing a few figures, answer the gentleman's question, but it would really be taking too much time. We are discussing too trifling matters. A minute is not an important item, although that minute is on my side. The point of real importance to such lines is not so much to gain a minute or two as to save a dollar or two. I do not want to save some picayune little cost of construction, nor to save this little distance nor that little curvature. The great point is that this plan will in almost all cases save an enormous proportion of first cost and curvature, and give a better line to operate simply by the freedom which it gives in location to pick and choose one's ground. Cheap as is the Mexican line I have described, for example, if I had been at liberty to use a few Y's I should have had a different location. I would not have saved the little sums I could have saved here and there, but I should have kept everywhere on different and far more favorable country, and I should certainly have saved more than half the cost. The chief saving is in the freedom to go where you please.

Prof. WOODWARD.—There is one other point I would like to ask a question about. I think the gentleman stated that the slack in the train would be taken up during the stopping of the train on the switch; that the rear cars would close up on the forward ones and that they would all close up on the locomotive. Am I correct ?

Mr. WELLINGTON.—Yes, sir.

Prof. WOODWARD.—Has this been tried ?

Mr. WELLINGTON.—That particular plan has never been used on a large scale. I have referred to where it has been used on a small scale.

Prof. WOODWARD.—If it is shown that in spite of the fact that the engine is hard at work, the cars push it up the grade at the end, then I would not have anything to say. But it seems to me that as the steam is not shut off at all, and the engine runs up to the last moment on a slightly increased grade, the train would still be in a state of tension, and that the thumping that would result from an instantaneous reversal of the locomotive on the down track would not leave the people in the rear car insensible of the whole business.

Mr. Wellington.—I refuse to assent to these various points, because, if I may say so, I have been over every one of them many times, and I have not got up here to advance a position that is somewhat contrary to accepted views without being pretty sure of what I am talking about. I regret that an honored professor of engineering should rise here and imply that nothing of the kind can be determined with any degree of precision without being actually tried. For if theory is good for anything, theory should enable us to determine certain things in respect to the effect of energy on the motion of bodies, without trial. If we must continue the discussion from the theoretical point of view, however, we will do so, and I will endeavor to act the part of a professor for the moment.

A train moving up a hill, at a uniform velocity, is in the condition mechanically of a body that is moving through space without any resistance whatever. The resistance of the air, the resistance of the wheels, is exactly balanced, and no more than balanced, by the power generated by the locomotive. Now then, that train, moving along in that condition, is, it is true, in a state of internal tension. The power is applied at the end which destroys the whole resistance. But as it rises it will be seen that the locomotive, the head of the train, is on a little heavier grade than the other. Therefore it is encountering a little heavier resistance and the rear of the train is encountering a little less resistance. It will therefore gradually close up upon, or tend to close up upon the locomotive. As the train comes to the stop, each car moving through space, and having less resistance to overcome than the locomotive, will gradually at the instant of stopping close up towards the locomotive. I have determined that theoretically, but it can be illustrated by a simple experiment. Let anybody take a stick and hang six or eight balls upon it, such as are often used in philosophical apparatus. Each ball may represent a car. Let him slide that back and forward on a straight line. Every time he starts or makes a stop there is a shock going through those balls. Now take those same balls, hung on the same stick, and string them on a cord, and hang the stick so that it can be swung as a pendulum, and you will find those balls will swing as smoothly as possible. There will be no shock between them; only, at the instant of stopping, the rear ball, not being elevated so high as the balls ahead, will communicate a certain amout of energy to the first ball and close up upon it.

Prof. Woodward.—I take it that we have had enough of this. I will not say anything.

Prof. Woodward.—Subsequently by letter:

I declined to continue the discussion for this reason. Mr. Wellington's illustration of balls on a string swinging under the force of gravity was so *mal apropos* that I did not think it worth the while of the Society

to have me play the professor and expose the fallacy of his reasoning. The lack of analogy between a train where all the force overcoming friction and gravity is in the locomotive, which transmits it down the train by draw-bars and couplings, and a string of balls where the force applied (that of gravity), is not transmitted at all, but is applied separately to each ball, was so obvious, that I felt that all but Mr. Wellington probably saw it.

His assumption that the cars of the train would close up on each other, and all close up on the engine, though the latter were under a full head of steam, even on a 3, 4, 6 or 10 per cent. grade, seems to me extremely wild. If the switches are reasonably suited to long and short trains, *i.e.*, if the increase of grade is gradual, and the engine does not come suddenly to a 20 or 30 per cent. grade, which it could not climb alone, the train would be in a state of tension to the last. It would stop when the engine was no longer able to draw it up so steep a grade.

Then, the train being in tension, and the steam instantly reversed, the locomotive would be sent back, not only with all the force of its enginery, but with the acceleration due to its steeper grade, and the result would be a shock, increasing down the train, much more severe than the engine could possibly give its own train on a level road.

Mr. Wellington.—Had my friend, Professor Woodward, ventured to assert upon his feet in the debate what he has added after some weeks' reflection, that he abandoned the discussion at the convention because he was satisfied that every one but myself saw that I was so obviously wrong in my position, I should have been ready to leave that question with the members present; but since he has seen fit since the meeting to raise that unnecessary if not inappropriate question, I will endeavor to show, in a few words, that if the Society did hold the view that Professor Woodward now thinks he thought they held, they were somewhat hasty in reaching it.

Few parallels can be absolutely exact in every detail. If essentially true, that is enough; but, fortunately, my parallel happens to be absolutely exact. The Professor has forgotten that I stated that "at the moment of coming to a stop" the reverse lever was to be thrown over. Interpreting the phrase quoted, I was clearly entitled to assume as understood that the locomotive was to be handled by a locomotive engineer in a proper way, and not by a lunatic, or man unfamiliar with it. Locomotive engineers are not in the habit of throwing over the reverse lever from full gear ahead to full gear back by a single motion of the hand, except in the last extremity. They do it gradually. But however they did it, by the wording of my proposition half the motion was to be complete (and the reverse lever on dead center) when the engine came to a stop. At that instant, therefore, and for a second or two before it, the train is in precisely the mechanical condition pictured by the balls, and it is that final instant which alone concerns us, for it is enough to insure gentleness in closing up.

But even without assuming that the steam was shut off at all before the stop, the Professor is still wrong, if his intention is to assert more than this: that reckless, unnecessary and improper handling of the engine might be made to give a disagreeable shock to the train; a point which, if it is deemed worth making, I am ready to grant, with the addendum that it is a possibility common to every kind of a stop and subsequent start.

Grant that the locomotive comes to a stop with the full steam on, from the effect of the rising grade. The locomotive will then stand on perhaps a 3 or 4 per cent. grade and the rear car on a 2 per cent. Hence the process of taking out the slack will have already begun by some relief of the springs. The reverse lever is then thrown back to or near to dead center—as it needs no words to show that any one in his sober senses would throw it, and not instantly to full gear back. What takes place? Paraphrasing Sir William Hamilton's famous bit of unconscious poetry:

> "There is no power, however great,
> Can stretch a cord, however fine
> Into a horizontal line
> That shall be absolutely straight."

We may say that there is no power, however great, can start that train, or any part of it, into rapid motion instantly. Even in closing up slack when starting a train by the power of the locomotive on a level there is no very violent shock, but in this case the locomotive is standing at the steepest part of the grade on a vertical curve, and the locomotive engineer has only to do what every competent man would do instinctively in such circumstances: wait for gravity to start the train before throwing his reverse lever into full gear back—to have the action of natural forces—with which I was justified in assuming that all Members of the Society were entirely familiar—close up the train with the greatest possible gentleness.

The attempted point therefore is, at the best, a distinction without a difference, although I think I have shown conclusively that there is not even a distinction, and I am, perhaps, under the circumstances, justified in adding that the usual process of speaking in haste and repenting at leisure has been reversed in this case by speaking at leisure words which it can be very quickly shown there is reason to repent of.

In closing the discussion I must express my regret that what was after all only a minor feature of the paper—the suggestion that a properly laid out switch-back system was the best for light traffic roads ascending to high elevations—should have occupied so disproportionate a space in the discussion. The extent to which a modification of the modern cable system might be applied with advantage to taking heavy traffic over high summits is, to my mind, a more important and more profitable point for careful attention, although both are important.

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TRANSACTIONS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

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(Vol. XV.—December, 1886.)

EUROPEAN SEWAGE AND GARBAGE REMOVAL.

By W. HOWARD WHITE, M. Am. Soc. C. E.

READ SEPTEMBER 2D, 1885.

I do not pretend to treat this subject at all exhaustively—as handled by Mr. R. Hering, M. Am. Soc. C. E., in his report to the National Board of Health in 1881, or by Mr. S. M. Gray, M. Am. Soc. C. E., in his report of 1884 to the City of Providence--but will give the Members of the Society the aspect of the subject which has presented itself to me during a somewhat prolonged stay in England and on the Continent, together with some remarks on the application of European principles to our own sewerage.

The accepted methods of handling sewage in vogue in Europe at present, and which have proved themselves more or less satisfactory by use during a term of years, are, generally speaking, five in number:

First.—The removal by wagon from privy-vaults directly to land which is fertilized by it.

Second.—Removal by water in underground sewers to the nearest river, or to the sea; the oldest and simplest of the more perfect ways of disposing of the sewage.

Third.—Removal by the same means to a neighboring river, with the interposition of works for the purpose of sufficiently purifying the sewage to render it inoffensive in the stream to which it is delivered while passing through the open country, or through lower-lying towns and villages.

Fourth.—Removal, as in the last two, to an area of land, over which it is discharged, and by the filtering or deoxidizing action of which, and of the plants thereon, it is purified before discharge into a convenient water-course.

Fifth.—Removal of the sewage in an undiluted or very slightly diluted condition to purifying works, where it is wholly or partially converted into high grade and inoffensive manures.

The first method is the primitive one, and still obtains in its most primitive form for the vast majority of the town and even of the city populations of Continental Europe; and for a large fraction besides in the cesspool form, the contents being removed by pneumatic process. The fecal matter is carried into the adjoining country by whole processions of long casks on wheels, and the roads adjoining European cities are rendered sweetly odorous by these fragrant caravans. This method may be said to prevail throughout all Germany, except in a few cities; such cities as Dresden and Munich being still largely treated in this way. The notable exceptions within my knowledge are Berlin, Hamburg, Frankfort-on-the-Main and Dantzic. Hamburg was among the earliest cities in the world to adopt the second method, and consequently the great majority of all the houses have water-closets.

The second method grew naturally from the covering in of the open water-courses and the provision of an ample pressure water supply. The water-closet then enabled the sewage to reach the nearest considerable stream through these covered water-courses cheaply, and not too offensively for immediate endurance. The stream then carried it off, and, if rapid enough, soon purified the sewage, so that it was no longer offensive—at least to the smell. This system found its way, therefore, almost contemporaneously with the introduction of a pressure water supply. Whether the Romans had any sort of water-closets is not known, but they used the second method largely in some form, and all the large cities of Europe have it to a greater or less extent.

The increase of population and the sluggishness of the rivers in Holland and parts of England, soon made the discharge into rivers a

nuisance to some extent, and brought about government interference, obliging the cities using the second method to modify it in some way to avoid polluting the rivers. This was done in London by its great intercepting sewers carrying the sewage down the river to what was considered a sufficient distance to avoid a nuisance to London itself, or to the large towns below it on the river. This, however, proved only a makeshift, as the pollution increased in a double ratio: first, from the increase of the sewage itself; and secondly, from the removal of the water of the Thames above the city for its water supply, thus diminishing the flushing power of the stream to a serious extent in dry seasons. How far this is true may be seen from some recent experiments with a new method of observing the rate of movement of sewage (by Mr. R. W. Birch), reported in *Engineering*, May 23d, 1884, in which he states, as the result of his experiments, that the sewage discharged into the Thames at Barking remains in the river during heavy floods for twelve days, and in dry weather thirty-two to thirty-three days. So the sewage of four to five millions of people for a month is generally to be found distributed along the river from Barking to its mouth, a distance of about thirty miles, averaging perhaps two miles in width, and, of course, much more concentrated at the upper end than below. As in the meantime the stuff is carried backward and forward in the estuary for about a month, a large part of the solids must become incorporated with the mud-flats, although the river conservancy has as yet made no complaint of silting up from this cause. The question of an extension of the intercepting sewers to some point nearer the sea, and of extending them upwards along the river to help out the towns above, which are now shut out from the use of the river as a sewer, is much mooted.

Large cities like Leeds, Manchester and Birmingham, lying on small rivers, and further from the sea, have been already forced to adopt other means of disposing of their sewage. Leeds and Birmingham have adhered to the water carriage system, but have resorted to artificial purification methods, of which they have tried a variety, but all unsuccessfully as far as the production of a manure salable for more than the cost of producing it is concerned. They have, therefore, abandoned for the present the attempt to produce a salable manure, and Leeds contents itself with precipitating the solids and neutralizing the liquids with milk of lime. The result is so far successful that the water delivered to the Aire is as clear and inodorous as that of any ordinary country

brook, and is without color, except when the dye-works of the city are in full operation. At such times it remains transparent and odorless, but has a very perceptible color. The defective feature of the process is the accumulation of sludge, which is only valuable as manure on very rank lands, and consequently finds a very indifferent sale. It is found, however, at Leeds that the farmers will remove it from the works if given away, and its disposal is therefore provided for, if the idea of profit from it be abandoned.

It is also claimed that the apparently inoffensive effluent will become again putrescent if discharged into a sluggish stream where its progress to the sea is slow.

The cost of the process to the city in 1884, including pumping, was $24 700. As the works cost $287 720—including part of experimental works no longer used—there is, at 5 per cent., an interest charge of $14 386, or a total annual cost of $39 086 for all expenses of taking the water from the intercepting sewer and returning it to the effluent conduit in a clear and inodorous condition. In 1884 the feces of 176 334 people were removed and purified at the above cost, making the cost per head per annum 22 cents; and of removal of dry privy matter the cost was, in 1879, for Leeds 24 cents per head per annum. The latter includes the removal of ashes, rubbish and garbage.

This, of course, does not fairly represent the matter, as the dwellings of 305 324, of the total population of 327 324, lay in the sewered district, and probably the vast majority of these discharged their slops into the sewers, causing nearly as much expense to the wet carriage system as if they had discharged fecal matter as well into the drains; and the sewers served also for surface and ground-water drainage. If the present cost of the wet carriage provided for all the sewage of the 305 324 served by it, the cost per head would be reduced to 13 cents, and it is safe to say that this would not be increased more than 25 per cent. by the increased service, or to say 16 cents, only about 66 per cent. of the cost of removal of dry excreta with the ashes and garbage, but without the slops or the purification of the latter. I have omitted in this calculation interest on the cost of the sewers themselves, or the cost of maintenance of the same, because these sewers are required at any rate for slops and surface and ground-water, and their use for fecal matters is only a convenience and part of the advantage of that system, and not justly chargeable to it. Practically, the same expenditure would be required for the sewers when dry removal is practiced.

It therefore appears that however expensive such purification processes may appear for large cities, there is a large margin of expense over the cost of dry removal with which to meet the removal of rubbish and garbage, even if future improvements do not make the sludge salable as manure. This too, apart from the immense advantage to health of the immediate removal by water.*

The details of precipitation, as practiced at the Knostrop works of the Leeds Corporation, which are a model of neatness both externally and internally, are as follows:

The sewage, on entering the grounds of the purification works, is passed through an open well with a grating in it, which intercepts all floating material. It then passes directly to the pump-well, into which the milk of lime used as a precipitant is run in a steady and continuous stream, in quantity determined by tests taken at regular intervals of the effluent quality. The sewage is dammed into the pump-well up to a certain height by a sluice. When its quantity exceeds a certain amount it overflows directly into the river, and at such times purification is suspended, as the sewage is too dilute to make it necessary. The pumps, which are Gwynn centrifugals, raise the sewage mixed with the lime 18 feet, and deliver it directly into the settling tanks by a circular main 3 feet in diameter. There are three pumps, each having a capacity of thirteen million gallons in twenty-four hours with the above lift. Two of them are generally kept in operation. In dry weather one pump working twenty hours does the work. The minimum flow from the city is nine million gallons per day. In heavy rains it rises to one hundred and ten millions or more, which must be somewhere near the capacity of the outfall, which is 8 feet high by 7 feet 9 inches wide, with a fall of 1 in 1 634.

The latter will therefore serve an enormously larger population than the present one, by using overflows from the intercepting sewer. It has also been proposed to diminish the amount of pumping required by building high level intercepting sewers to take the sewage from the upper parts of the town directly to the settling tanks.

The milk of lime used consumes 126 tons of lime monthly, and is made with enough water to run very freely. It is mixed in circular vats

* To get at the actual annual cost of the Leeds sewerage system per capita, 5 per cent. interest on the $1 892 280, which the sewers have cost, or $94 614, and maintenance cost of sewers proper of $4 000, must be added, making a total of $137 700 per annum for the removal of the water-borne sewage and storm water, and the purification of the same for the population of the sewered district (305 324 people), or 45 cents per head.

with vertical revolving stirring shafts, with horizontal arms, and is delivered from the mixing vats directly into the pump-well, which has been found the most satisfactory way—the first process, of delivering into the pump inlets, where it was agitated by a mechanical stirrer, not having proved of practical advantage.

A 20 horse-power engine serves for lime mixing, and for hoisting of water and materials. The lime has suitable storehouses and slaking bins provided, and a railroad siding gives ready access for supplies.

The 3-foot main above mentioned discharges into an open channel, with six tanks on either side. This channel has cross-gates at the division lines between the tanks, and also into each tank; and the tanks can also be cut off from each other by flash boards, so that the sewage can be directed in any desired course through the tanks, and into and out of the main channel. Thus any tank can be cut out of circuit for cleaning, while the sewage takes its usual course through the others, passing around the empty one through the main channel. Eleven of the tanks are 100 feet in length along the channel, and 60 feet at right angles to it; the twelfth being only 88 feet long and of the same width as the others. The tanks have concrete foundations, clay puddle walls and floors, and are paved, sides and bottoms, with stone.

The regular course of the sewage is into the first tank to the right of the channel, and from tank to tank over brick partition walls, capped with stone, into the sixth on the right, whence it crosses and returns from the sixth to the first on the left in the same way. The first on the left, or No. 12, has an outlet weir, over which the sewage flow is regularly gauged. After the tanks had been arranged as above, it was thought best to utilize five acres of adjoining land by converting it into a final settling basin before letting the effluent go, when the sewage seemed to need any additional purification. To do this, and at the same time not to interfere with the weir action, the late Mr. Morant,* Borough Engineer, devised an ingenious trough sluice. This is a rectangular structure, closed at one end, built of boiler plate and angle irons, and running on rollers over the waste way.

By racks and pinions it can be moved under the lip of the weir by an attendant in one minute, when the effluent is discharged into the

*I am indebted to the reports of Mr. Morant and of Mr. Hewson, the present Borough Engineer, and to notes furnished kindly by the latter, for such information as I did not get from personal observation.

auxiliary reservoir. When moved away, which is done with equal readiness, the water flows freely into the waste-way.

A good current through the tanks is obtained by dropping each division wall two inches below the preceding one; and to prevent the fresh sewage from running in a thin sheet over the stagnant water in the tanks —found to be a source of imperfect action at first—the third and seventh tanks contain cross walls built to the full height of the sides, and with openings at the bottom, by which the sewage is forced downwards, and the onward movement of the whole body of liquid maintained. Beneath the center channel is a subway 6 feet wide by 5 feet 8 inches high. In this is a cast-iron pipe, 18 inches in diameter, with 12-inch branches to each tank, provided with gates placed in the tanks at the level to which sludge is allowed to rise. For cleaning any tank it is cut out of the circuit, and the liquid is drained through the above gates and carried back to the pump-pit. This done, a 24-inch gate at the lowest corner of the tank is opened, and the sludge is swept through it and a pipe in the subway to a pump-well, whence it is raised 16 feet to a movable chute, which delivers it to the drying ground, where, according to the present process, it remains until removed by any one who wants it.

The twelve tanks have a united area of 71 270 square feet and contain two and a half million gallons. The smell from them is very slight, the strongest smell about the premises being in the pump-room, where it is by no means unbearable. The first five tanks are cleaned every five days, and the sixth and seventh about once a week. The remaining tanks seldom require cleaning, the deposit being never over an inch. They are emptied four or five times a year, to change the water effectually. When ready for cleaning, the mud in No. 1 averages 21 inches deep; in No. 2, 18 inches; No. 3, 10 inches; No. 4, 6 inches; No. 5, 5 inches; No. 6, 4 inches.

In the elaborate works on this system now in progress for Frankfort-on-the-Main, designed by Mr. W. H. Lindley, the distinguished successor to his father's reputation in this department, the sewage is divided over the whole precipitation space, entering three tanks, comprising the whole area, at once, instead of passing in succession from one to another. This process gives a slower velocity to the sewage than the other; which, if attained, will probably be more advantageous. It seems probable however, that some measures will have to be taken to prevent the surface flow referred to above, no provision being as yet

made against this in the Frankfort works. It can be readily introduced afterwards if found necessary. Four tanks are provided, as one is always liable to be in process of cleaning. Mr. Lindley has been able to so arrange his levels, by taking advantage of the rapid fall of the Main, in putting his works some distance below the city, that it will only be necessary to pump the sewage in times of excessive flood, and for the purpose also of emptying the basins to be cleaned.

The expense of the Frankfort works has been considerably added to by the assumed necessity of vaulting over the basins on account of interference with cleansing by ice formation. It would seem not impracticable to use scrapers for dragging the sludge to the sludge pumps, operable under the ice by machine power.

At Frankfort it is proposed to use as a precipitant chiefly sulphate of alumina, in the form of alumino-ferric. The effect is as follows: The acid of the alumino-ferric is set free by its reaction with the alkaline matters in the sewage, and the alumina, through its affinity for the organic substances in solution, precipitates the latter in solid form. As the alkalies in the sewage are not sufficient to neutralize all the acid in the sulphate, enough lime is added to render the whole action of the alumina available. Where a great deal of acid is contained in the sewage, as where certain manufactures and dyeing processes are carried on, as much lime is needed for this process as would suffice for the entire precipitation, hence it is not practicable.

Its advantages, when practicable, are, as given by Mr. Lindley, to whom I am indebted for many courtesies:

First.—It precipitates impurities in solution as well as those suspended.

Second.—Its effluent is not so liable to after-putrefaction.

Third.—It does not make so much sludge as the lime process.

Fourth.—There is less danger of the escape of free lime in the effluent.

The smaller towns, which were favorably situated for the purpose, made use of simple irrigation for purifying their sewage with success, and I think there is little doubt that this is the best solution of the question for smaller inland places.

The entirely favorable conditions are that the place shall lie high enough to give a natural drainage into irrigation ground also lying high enough to be drained by subsoil drains at least five feet below the surface.

The process can be applied by pumping the sewage when the town lies too low to fulfill these conditions. The depth of drains for the irrigation ground is determined somewhat by climatic conditions. The town of Harrogate, in Yorkshire, England, with a population of about ten thousand is a good illustration of the sewage broad irrigation process. It has an exceptionally favorable situation, lying very high, and with its sewage farm in the immediate outskirts, also lying high enough to receive the sewage over almost its whole area, and at the same time with slopes steep enough to cause a rapid circulation and rapid drainage. The ground used is about two hundred and thirty acres, upon which is delivered the whole of the sewage and a part of the storm water as well. At ordinary times the sewage is satisfactorily purified (the effluent is not entirely inodorous) before reaching the drains, which are four feet underground. In dry weather, however, when the ground cracks, the effluent is unsatisfactory, and the authorities are of the opinion that the drains should have been placed six feet deep instead of four. As this is in the moist English climate, it appears certain that with land as sloping as this (averaging about 1 in 14 to 1 in 16, from my recollection), in the American climate the drains could not safely be put less than five feet deep, and probably six to seven would be expedient. If, on the other hand, flatter land be used, the drains might be at less depth, but more land would be required.

In this connection a curious fact is of interest. The sewage as it reaches the farm, after running perhaps half a mile from the thickly settled part of the town, comes out simply as a turbid stream, and leaves no undissolved constituents like paper after soaking into the ground. On an occasion, however, when the sewer was broken in the immediate vicinity of the town, the ground in the neighborhood was covered with paper. The town authorities deduce from this that all the matters going into the sewers are dissolved or ground up in the passage, but it appears to me more probable that a silting process is going on in the sewers, which was to some extent interfered with and remedied by the break, which was, I believe, caused by a flood in the adjoining stream. At this time it might be presumed that an unusual body of water was passing through the sewers, though they are not to any great extent the carriers for the storm-water, which is otherwise provided for. In long water carriage the paper and other matters do undoubtedly lose consistency, but half a mile is too short a

transport to account for the difference between an undissolved condition, and entire disappearance of these matters.

The description of the Harrogate system will show the difficulty of introducing it for cities of 100 000 or more. If we could find land equally favorable in its neighborhood, a city of 100 000 would require on the same basis not less than 2 000 acres for irrigation.* As the system involves deep sub-drainage, and at least partial control of the way in which the sewage is laid on, which must be done with regard to purification, rather than to production of crops, it becomes apparent that the system would be expensive in first cost, and a very cumbrous one to handle. This will be still more evident, since the area required for 100 000 people would generally be far more than the 2 000 acres of the exceptionally favorable Harrogate basis, even with artificial elevation of the sewage, and could not be found in one compact body, but must be selected in several places, more or less remote from each other. This because the flatter area, while more perfectly purifying the sewage, becomes more easily flooded and unfavorable for cultivation.

At Harrogate the sewage farm is worked by the city, and proves fairly remunerative for the capital put into it, but it is not used as a Poor Farm, with which it might generally be combined in our towns of a similar grade.

Features favorable to irrigation in the United States are, first, the ameliorating effect on frost in the ground of the winter flow, which experience shows to be of such high temperature as to have a decided thawing effect; and secondly, the dryness of our summers, which would make the advantage of irrigation greater in that season.

A modification of irrigation, for the purpose of reducing the area required, is the filtration method, suggested by Dr. Frankland in 1870, and first practiced by Mr. Bailey Denton immediately afterwards. The land occupied, instead of being simply sub-drained, is first chosen with regard to its porous character—chalky or sandy soil is best—and its favorable levels. It is then divided into four plats of equal area inclosed by low embankments, upon which the sewage is discharged in succession for equal periods of six hours each.

The accepted minimum area for this method of purification is one acre to 1 000 persons, and the sewage of the town of Kendal, Westmore-

* One thousand has been thought sufficient by some competent authorities.

land, with 10 000 people, has been purified on this plan for about ten years with 850 people per acre, the effluent being clear and inodorous to the present time.

Certain kinds of crops can be raised on this land, but a profit is not expected from it, and where the sewage is discharged upon it in a crude state, it seems a question of limited time only when it shall become too much choked with sludge to work efficiently. It is now generally recommended for large places only in combination with preliminary precipitation, as in the report for 1884 of the English "Royal Commission on Metropolitan Sewage Discharge," where it is proposed to establish precipitation works at the present outfall of the London sewerage at Barking, and to discharge the effluent over a filtration area, from which it will be presumably again discharged into the Thames; though the Commissioners are rather vague upon this point, and indeed appear to have gone but little into the details of the scheme, which involves acquiring not less than 3 500 acres of land of suitable quality, from which little or no return can be expected, and which must be prepared at an average cost of $350 per acre,* the land itself, if obtained within a reasonable distance, costing at least $1 000 an acre. On this basis 3 500 acres would cost, ready for operation, about five million dollars, with only a moderate allowance for a conduit to the filtering ground. The interest on this at five per cent. would be $250 000, and allowing the cost of maintenance as $3 000, the annual cost per capita for 5 000-000 people would be five cents. Adding this to the sixteen cents which we allowed for Leeds precipitation, we have a total of twenty-one cents per head per annum. Now it is clear that the cost of carrying a sewer out into deep water of the English Channel would not be more than $500 000 per mile, as numerous railway tunnels over a mile in length have been built for this figure,† or $22 500 000 for forty-five miles, including submarine outlet three miles in length. The interest on this at five per cent. would be $1 125 000. The total annual cost of this per head of a present population of 6 000 000 in the Thames Valley would be 18.8 cents, allowing for maintenance, say nineteen cents. To this must be added eight cents per head for pumping to place it on the same basis with the filtration estimate, and we get twenty-seven cents per head against twenty-one cents for filtration.

* Average of Mr. Bailey Denton's experience.

† The last great tunnel, the Arlberg, in Austria, cost $813 000 per mile for 6⅜ miles.

If now it is considered that the above cost of the outfall to the sea would probably cover a conduit for a future population of ten millions—or if not, could be made to for a slight additional percentage—the cost per head for that population would be, say, 12 cents for construction and maintenance, and 8 cents for pumping, or a total of 20 cents, against 21 cents by filtration. This last figure does not entirely represent the figure for increased population, for a suitable increase of land could probably only be had at a greater proportional expense, while other expenses would rise proportionately to the increase of population.

It is also to be considered that some return might be expected, as time went on, for supplying irrigation water to lands adjoining the conduit to the sea.

From this comparison I conclude that it would be more profitable for London to extend its intercepting sewer into the ocean, where the purification is always certain, if the sewage is discharged at a sufficient distance from the shore, which distance need never exceed a practicable amount.

Recent experiments on the effect of dilute sewage on fish indicate that even those generally supposed to live only in perfectly pure water flourish better where some organic matter is carried, and that a stream or body of water in which the percentage of sewage does not exceed a certain limit will support more fish than where it is absent. If this result is confirmed, it would be a still further argument for the discharge of sewage into large bodies of water in which this interesting means of converting sewage into food exists.

Owing to the element of uncertainty how long a filtration area will remain available, it seems to me a matter of much serious consideration whether filtration without preliminary precipitation is at all practicable for cities too large for irrigation, and too distant from a large body of water for direct discharge into the same.

The fifth method, in its simplest form, is practiced on a larger scale than anywhere else in Manchester, England, where the excrement, solid and liquid, is deposited in pails, into which are placed at irregular intervals—usually daily—the house ashes, with the object, attained partially at least, of deodorization. These pails, fitted with air-tight covers, are removed twice a week or oftener to a depot in the outskirts of the city, where by a variety of processes, chemical and mechanical, the refuse of the city, including the market garbage and dead animals,

as well as the feces, is converted chiefly into a high grade manure, sold at £3 per ton delivered within 150 miles of the city, and otherwise into a great variety of materials like mortar, soap, oil and candles, all of which, except the mortar, are used up by the city itself. I have not been able to get very satisfactory pecuniary statistics as to this process. So far as it appears from documents available to me, the cost of disposing of the dry closet refuse and garbage for the city for the year ending March 31st, 1882, was $185 460. This seems to have been the gross cost before deducting sale of mortar and manure. Sales of 7 000 tons of manure, say at $13.50 net, give $94 500; 9 368 tons of mortar at $1.25, equal $11 710; total, $106 210; leaving, as the net cost of the establishment, $79 250, less an uncertain amount for other products of the sewage used by the corporation. The cost of the works was $600 000. Interest at 5 per cent. is $30 000, or a total annual cost to the city of $109 250. If this dry removal cost the same per head as at Leeds, it would amount to $70 800, leaving $38 450 to be accounted for by the other products of the sewage, or by excess of cost over the Leeds dry removal.

Now the population of Manchester is 350 000. There are 11 000 water-closets. I assume five persons to a water-closet. This is probably not too small, since they are largely used by a day business population of 150 000, which is additional to the resident 350 000. Taking out then 55 000 served by water-closets, we have 295 000 using dry-closets, giving for a total annual cost as above of $109 250, an annual per capita of 37 cents. As this, however, covers garbage and ash removal for the population using water-closets as well as those served by dry-closets, the only deduction that can be made from the above figures is that the cost of dry removal of feces and garbage in Manchester is probably somewhere between the Leeds figure of 24 cents and the 37 cents above found. The advantage gained by the extra expense, if the cost is any greater, lies in the rapid removal of the putrescent matters from the premises instead of keeping them for long periods in vaults. It is to be noted that the above per capita includes not only, as in Leeds, the carting of dust and refuse, but also the cost of getting rid of dead animals and other organic refuse by destructors, an item which I have been unable to separate from the other expenses.

The Liernur separate system, when conducted in its best form, costs for actual running expenses 22 cents per head of population served, ex-

clusive of interest on plant and dust and garbage collection;* so it is evident there is no material advantage, if any, in the latter on the side of economy, and it is probably considerably more expensive than either well conducted dry removal or the combined wet-carriage system.

In summing up the conclusions to be drawn from European systems, I think it safe to say that dry carriage can under no conditions be either economical or healthful, though it may be made, as it has been in Manchester, a great amelioration of the old privy system.

In general the combined system of wet carriage seems expedient for closely built cities or quarters of the same. This statement supposes sizes of branch sewers large enough to carry the sewage and to clear the streets of ordinary rains, and the provision of overflows for interceptors such that the latter shall not be weighted with more water than is desirable to carry the sewage proper and to clean them.

The separate system finds its natural adoption where the slopes of a city are so steep, or the town sufficiently rural, and likely to remain so, as to make it practicable to carry the storm-water by open gutters into natural water-courses. This applies to parts of cities and towns as well as to the whole. Thus a city might be advantageously provided with the combined system in a flat business portion, while steep streets in a dwelling quarter could have drains for sewage alone. In a city where combined sewerage is used, however, it would generally be undesirable to adopt a separate system for a dwelling quarter merely on account of thin population, when topographical reasons were absent; since the rapid alteration in the character of cities, particularly in the United States, makes the present character of a city district of little value in determining its drainage system.

As to the disposal of the sewage. If a city is near the sea or a great lake, I have no hesitation in saying that those bodies of water are the natural receptacles of the sewage.

This can be discharged in a small town on the shore of a body of water directly into the same at any convenient number of points, with such disposition of grades, however, as to allow eventual intercepting sewers with a single outfall.

The latter could be extended further into the sea or lake as the city increased in size; or, if the character and thinness of the coast settlement admitted it, be carried some distance along the shore, as at Brighton,

* See Hering on Amsterdam sewerage in 1880.

England, and carried further away as became necessary. Such prolongation of an outfall beyond a limited distance would, of course, generally involve pumping to give discharge head.

Where direct discharge into a sufficiently large body of water is inadmissible, irrigation is the first method expedient. It is generally limited only by the size of the city, since pumping makes the attainment of a suitable area for the same always possible where the town is unfavorably situated for direct discharge over an irrigation area.

As the city found its irrigation becoming unwieldy, or the acquirement of land too expensive, recourse could be had to preliminary purification prior to irrigation, which could then become filtration in part, and more and more as the amount to be disposed of increased. Berlin is fully launched in the first stage of this process. Whether it is feeling at all pressed towards preliminary purification can probably not be known by the outsider, but it may be fairly assumed that even the 13 222 acres owned by it in 1884 as an irrigation farm will before long be fully occupied in handling the rapidly increasing population of the German metropolis, even with the partial use of filtration already introduced.

It is impossible, however, to lay down hard and fast rules to fit all cases. Dantzic, whose sewage farm lies directly on the sea—the city itself being not far distant—was clearly right in adopting irrigation, since it was able to obtain an area of but little more value than beach sand, which its sewage on the way to the sea has converted into a profitable farm, whose products pay the entire cost of pumping and of the maintenance of the sewerage system.

The City of Providence, under Mr. Gray's advice, declines to irrigate, because, although the body of water near it is too small to admit direct discharge, it is large enough to take purified sewage at less expense than would be caused by pumping to distant irrigation fields, only to be found at a pretty high level.

Boston has wisely chosen the sea discharge, and New York and the neighboring cities will probably have to do the same at some future day, though their exceptionally favorable situation may postpone it some time. Chicago, if I am not mistaken, will find discharge into the lake several miles out, the solution of its difficulty. Discharge rearward into the Desplaines River cannot be long endured by the population along that and the Illinois River. In regard to the dwellers on the Mississippi who congratulate themselves on the possession of a sewer outfall with

infinite dilution capacities, I think it can only be a matter of time when preliminary precipitation must be resorted to, to avoid the nuisance caused by the deposit of filth along the banks and bars of the great river, and the injury to the drinking water drawn from it, though the time may be distant.

European sewage depends too much on hand cleaning. Sewers should, of course, be inspected regularly, but a well arranged system of sewage should, with little exception, clean itself, either by its normal flow, aided by rains, or by automatic flushing with ground or other water. To do this with certainty it is necessary either that the grades should be so laid that no diminution of velocity ever takes place at any point in the sewage system, or that no particles shall ever enter which will not be carried by the least current velocity found anywhere. The former condition is generally impossible. As to sewage and slops, the latter condition can be generally, if not always, attained by the passage of the kitchen slops through grease-traps, after which the tendency of the fermenting sewage will be more and more to float without adhering to the sewer walls. Things thrown into the closets of a house will almost always float if they will pass the traps at all.

The latter should, of course, always be capable of being cleaned. Street washings are the greatest source of heavy deposits, and to attain the desired object we must prevent the entrance of particles too heavy to be held suspended at the minimum current velocity. For this purpose our old fashioned street basin, trapped by a dipping apron, is a more rational scheme than the various arrangements which have come into vogue in Europe, which either pass the street washings directly into the sewers, as at Paris, and involve most systematic and expensive cleaning, or else only very partially catch the washings in a small removable pot at the bottom of the little catch-basin used. The latter is generally covered by a grating which becomes stopped up by the paper, straw, leaves, etc., washed off the street in a heavy rain, and is highly successful in flooding the street around; and the velocity of the water passing through the basin is so great, that only the very heaviest particles are left in it. All this might be avoided by a combination of the three arrangements. In the first place the discharge from the street should be sideways through the curb (if in one direction only) and without a grate, so that the floating stuff could be carried into the basin where it belongs, and not stop the inlet. Secondly, to prevent the floating stuff getting into the outlet or

passing into the sewer, there should be a diaphragm across the catch-basin, dropping below the bottom of the outlet and rising close to the cover of the basin to catch this floating matter and to oblige all the entering water to take a downward direction. This should not, of course, close the basin at the top, but should allow free circulation of air to the sewer. The size of the basin should be so regulated that the diaphragm could be placed at such a distance from the outlet that the water in reaching the latter when fully filled, should have no greater velocity than the minimum maintained in its after passage through the sewers. The basin velocity could generally be reduced to one-half the after minimum without making the basin of excessive size. This would cause the precipitation of all the heavy particles from the street water into the bottom of the basin, which should be fitted with a removable receiver. The diaphragm being made removable also, the receiver could be hoisted out by a derrick attached to the rear of a wagon, and the contents discharged into the latter. The sectional area of the catch-basin on the inlet side of the diaphragm should be arranged so as to afford sufficient room for floating matters without causing such a velocity of the inflowing water that they would be sucked under the partition.

It is difficult to see, under such a system, how any material could stop in the sewers themselves, and certainly nothing whose presence could foul the sewer in the interval between hard, flushing rains. The possible escape of substances of a bulky nature under the diaphragm and into the outlet of the basin could be prevented by a grating over the latter.

That the deposition of sediment in sewers depends almost entirely on such regulation of velocities, is shown by the experience with the numerous siphons under the river channels in Dantzic. The siphons are provided with a basin at the entrance arranged on the above principle. The sewage falls upon a horizontal apron and passes with very slow velocity to the mouth of the siphon, with the result that in fourteen years use these siphons have never required cleaning, all floating matters being caught on the apron and heavy ones being dropped into the bottom of the basin.

The more usual practice as to overflows in Europe is to place them practically at the top of the sewer. In view of the fact that matters in the sewage not yet reduced to solution or to very fine comminution generally float, a better arrangement of the overflow would be a long narrow opening at the lowest point at which the sewage was considered

diluted enough to permit it to overflow. The opening could be made narrower than called for by weir action, the head of pressure above it giving a larger discharge. The effect of this would be to allow the escape of the foulest sewage only at such time (generally short) when the quantity flowing was constant and just filled the sewer to the overflow point. Above that level the floating matters would overrun the overflow, the water below being tapped off. Such an opening might be screened also with wire netting, since the scouring action of the current along the sewer would clear it of such material as did not force its way through.

An ingenious arrangement has been devised by Mr. Hewson, the Borough Engineer of Leeds, for letting off the overflow somewhat as recommended above, but with the additional feature of a gate closing the main in proportion as the overflow carries off the water. The apparatus is as shown in the cut, Figs. 1 and 2, Plate LXXXVII. The sewer (presumably a branch about to enter the interceptor, or it may be the interceptor itself), enters a chamber rectangular in plan. The invert is carried unbroken through the chamber into an outlet in line with the sewer whose surplus is to be carried off. This outlet is considerably smaller than the sewer it serves, being intended to carry only the sewage proper, with a certain allowance of dilution, into the interceptor, or into the sewer continued,

On one side of the above chamber is the outlet for the flood water. This is shut off during the normal flow of the sewage by a box, either of wood or metal, forming one side of the sewer. This box moves up and down in grooves in the chamber walls, and is connected by a chain and sheaves to a gate across the outlet of the sewer proper, in such a manner that when the box is in a closed position, forming one side of the sewer, the gate is wide open. As soon as the flow increases above a certain level in the sewer, the box floats up and allows the sewage to run off below it, at the same time partially closing the regular outlet. Eventually, in a heavy flood, the regular outlet would be entirely closed and the entire flow would pass through the overflow. This overflow offers a considerable advantage in opening always below the water level, and in adjusting its opening to the water to be passed through. The advantage of the gate across the regular outlet lies therein, that when it is closed the whole capacity of the sewer beyond this outlet will be called for in carrying the local storm water, and by the use of such gates the

AUTOMATIC OVERFLOW, LEEDS SEWERAGE

PLATE LXXXVII
TRANS. AM. SOC. CIV. ENG'RS.
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WHITE ON EUROPEAN
SEWAGE AND GARBAGE REMOVAL.

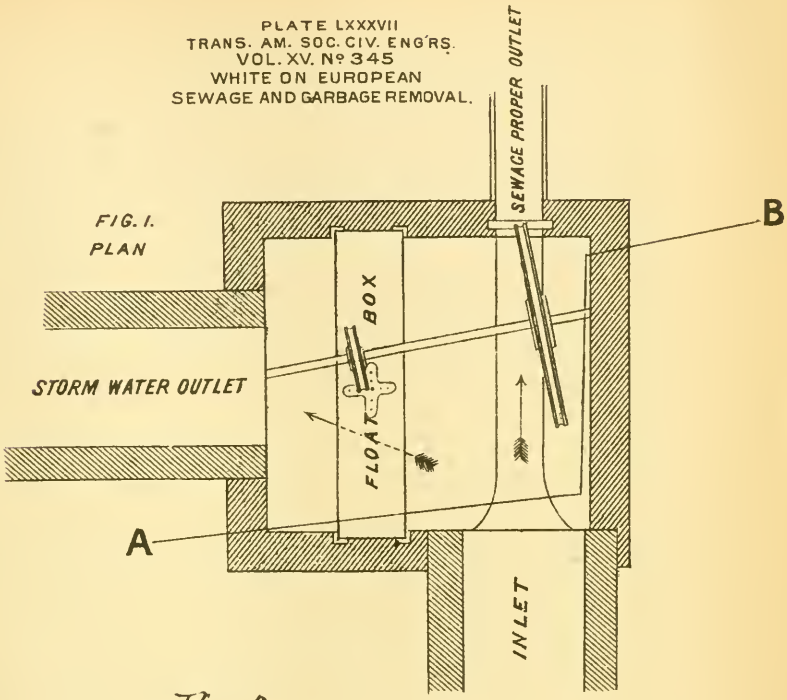
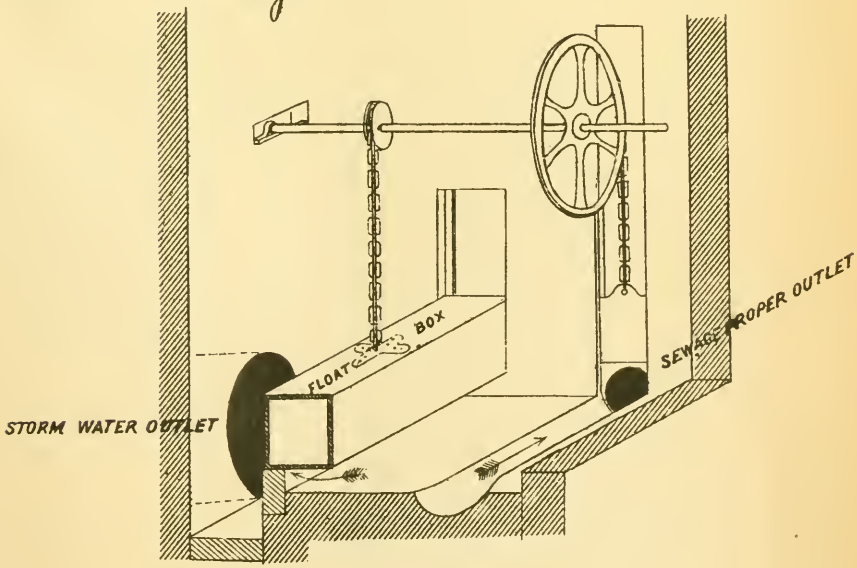


Fig 2.



SECTION A.B

intercepting sewers might be made little, if any, larger than called for by the normal sewage flow.

Of the practical working of these gates I have no particulars, and their advantages largely depend upon how much they can be trusted to operate infallibly.

Mr. Hering recommends in his report, overflows in the line of the sewer; the latter being deflected at this point. Apart from the accumulation of any bulky matters which might be passing through at such points, such a position would certainly lead to the discharge of the matters most desirable to keep in the sewer.

Sewers which have to be made large enough to enter could be made with advantage, and at small expense, large enough to carry the water-pipes and electric wires, and even gas-pipes when the sewers are thoroughly ventilated at the top of the same. The size should be such that, except in extreme rains, repairing operations on pipes, etc., could be carried on by floats made for the purpose, or on portable platforms. The expense of such enlargement would be small compared with the saving of street upheaval and interruption, and in view of the readiness of repairs at almost all times.

There is one matter of ventilation in which I think European systems are generally wrong, while the American ones are, to my mind, not entirely right. Many or most European cities ventilate sewers partially through house soil pipes; we, on the contrary, with few exceptions, and rightly I believe, cut off the sewer from the houses by traps.

In explaining where I believe our practice is wrong, I will begin by inquiring what the object of ventilation is, for this object seems to me to have become partly obscured under the word ventilation, which has here a somewhat different meaning from its usual one. In sewers large enough to enter, the object is to keep the sewer air pure enough to breathe without danger, and to avoid having it enter the living rooms of our houses, no matter how good its condition. In sewers too small to enter, the latter object is the sole one, and this applies to house drains.

First.—The object of house-drain ventilation is often stated as the greatest purity of the air of the drains and pipes. Now, for my part, the condition of the air in the drains and pipes of my house does not interest me so much as that of its rooms, and my aim is, therefore, to so organize the condition of these drains and pipes as to avoid any possible exit of

the air from them into the house, and to insure an in-draught into the drains if any leak occurs, or if any opening is made into the same by the emptying of a trap, or by some other cause. I begin, as usual, by carrying up a ventilating pipe of suitable proportions alongside my kitchen chimney, the lighter air in which is, as it were, a negative weight always hung on one arm of the air-balance to insure its dropping in that direction if the other end is let go. The next question is: Shall I make other openings from the outside, or from the house into the drain for air circulation? Why should I? If a leak occurs, or if a trap goes dry, such openings would only defeat the object for which I have put in my kitchen-chimney ventilating flue, since they would diminish the suction I aim at.

Second.—If such openings are from the outside, the cold air will be passing through my house in a steady stream, and as the soil-pipes, for practical reasons, are almost always immediately adjacent to the water-pipes, the latter will be liable to freeze in cold weather, a thing which has been actually known to occur in Chicago and elsewhere, owing to this arrangement.

Third.—Do I need such a current to remove germs of disease? No. The flushing action of properly arranged closets is much more effectual than any such circulation, and if anything bad is liable to germinate in the hot, dry, kitchen flue, the puffs of air forced through every time the soil-pipe goes into action will remove them. Furthermore, the air-balance prearranged and assured by the warm column in the sole ventilating flue, makes it impossible for such to pass off, except into the sewers or up the kitchen vent.

I therefore conclude to keep my drains as nearly as I can in the condition of an exhausted receiver, into which the air from the house will pour if any opening is made.

The only cases in which it appears possible to have an escape of air from the house-drains backward into the house through this arrangement, are in the phenomenal event of a close stoppage of the kitchen-chimney ventilating flue occurring at the same time with dry traps, or at a time when the house is not occupied, causing coldness of the kitchen chimney.

The disposal of dead animals, garbage, dust and ashes not suitable for the sewers, and difficult to get rid of by dumping, is a matter which, so far as I know, has been handled with us in the crudest manner, and the same is true generally of Europe.

In 1877, there was built at Leeds one of the so-called "garbage destructors;" and either shortly before or after, the same apparatus was put up at Heckmondwike, Blackburn, Bradford, Warrington and Derby in England, and at Kralingen, near Rotterdam, in Holland. The first destructor at Leeds was erected at Burmantofts, two miles from Leeds Town Hall, in a northeasterly direction, and the second at Armley road, about one mile westerly of the same point. The destroying furnace is the Fryer Patent Destructor.

For a description of this I cannot do better than quote from Mr. Hewson's report of 1884, from which the plans accompanying this, Plates LXXXVIII, LXXXIX and XC, are also taken.

"The destructor consists of ten compartments (at Burmantoft) or cells (five back to back) formed of brick-work, lined with fire-bricks, and tied with iron rods; it occupies a space of thirty-six feet by twenty-four, and twelve feet in height, and is so arranged that there is one inclined road leading from the adjoining road up to a platform, against and higher than the top of the destructor, on to which the refuse is carted, and another inclined road leading from the same adjoining road down to the level of the firing floor, by means of which the mortar, charcoal, old iron, etc., is carted away.

"Each of the cells is capable of destroying six tons of refuse in twenty-four hours, and consists of a sloping furnace with hearth and fire-grate covered in by a reverberatory arch of fire-brick, with one opening at the top for the admission of the refuse, and another opening at the side, near the top, for the gases to escape into the flue, and a furnace frame and doors for the withdrawal of the clinkers. The refuse, which is tipped on to the top cells, is pushed down the incline or throat with a long iron prong, and slides forward on to the sloping hearth, whence, when sufficiently dry, it is helped forward on to the fire-bars, where it burns somewhat fiercely, the fire-brick arch above concentrating the radiant heat upon it. The opening for the entry of refuse is divided from the opening for the exit of gases by a partition-wall with a bridge. These prevent the refuse, which is heaped up immediately below, from finding its way into the flue also. At intervals of about two and a half hours the clinkers are withdrawn through the furnace doors, but the charge of refuse is maintained permanently at the top. The effect of this is that no doors are required, the charge keeping down all smoke. The result of the process is that everything is consumed, or

converted either into clinkers or a fine ash. Every two cells are also provided with an opening (with doors) for the introduction of infected mattresses, diseased meat, etc., on to the fire, where everything is readily consumed without causing a smell in the works.

"The gases from the furnaces on the way to the chimney shaft pass through a multitubular boiler six feet diameter and ten feet in length, and make steam to drive a horizontal engine with twelve-inch cylinder and two-feet stroke, which works two mortar-mills with pans eight feet in diameter. In these the clinkers made in the destructor are mixed with lime and ground into an exceedingly strong mortar, which is readily sold at five shillings per ton. No fuel of any kind is required, the ashes mixed with the refuse being amply sufficient. The old tins and iron which have passed through the furnace are sold for old metal at from five to fifteen shillings per ton; but if collected and sold unburned, they fetch one pound per ton. This is on account of the solder value saved by non-burning.

"The clinker from the furnaces is 25 per cent., by weight, of the refuse consumed."

A carbonizer was formerly used for the special treatment of market refuse, with a view to converting it into a high grade manure; but as it was found that 80 per cent. of the charcoal obtained is simple earth, and therefore of little value as manure, the carbonizer was discontinued, and the whole of the refuse is treated in the ordinary destructor.

The original chimney at Burmantoft was about eighty feet high. As complaints were received of the smells from it, a new one, one hundred and fifty feet high, has been built; and in order to mitigate the discharge of dust over the neighborhood, the horizontal flue has been given the shape shown in the section *C D*, in which the depressions on the sides are to catch the dust, which is removed weekly through doors at the end of each block of cells. Since the rearrangement, no nuisance of any kind is reported.

The Burmantoft destructor consumed during the year ending August 31st, 1884, as follows:

Rubbish	1 538	tons.
Ash-pit rubbish	23 207	"
Beds	45	
Mattresses	96	

Pigs	58
Cows	9
Sheep	9
Quarters bad meat	4

This was the product of about one hundred thousand people. The cost was as follows:

EXPENDITURE.

	£	s.	d.
To cost, £7 282 1s. 1d. Repayment of debt by equal annual instalments of principal and interest during sixty years, at 3½ per cent	291	17	9
" Labor for one year	585	1	0
" Lime	34	18	4
" Depreciation, at 2½ per cent., covering repairs	182	0	6
" Gas, water, rates, etc	126	19	7
	£1 220	17	2

RECEIPTS.

	£	s.	d.
By Mortar	97	18	11
" Charcoal	20	9	6
" Scrap iron	14	15	11
Balance	1 087	12	10
	£1 220	17	2

The Armley destructor sold, for some reason or other, much more mortar, and, therefore, while its total expenses were about the same, the net cost of operating was only £842 4s. 6d.

To compare the cost of running these destructors with that of the removal of refuse otherwise, I will take the case of New York, where the removal of rubbish, etc., after being delivered at the water-front, to deep water, where it is now dumped, costs from $175 000 to $200 000 annually for a population of about one million five hundred thousand. As the cost in Leeds is about $50 per one thousand per annum, the same rate applied to New York would give $75 000 per annum. The circumstances in Leeds are, however, much more favorable than in New

York, since the city has a thinly settled suburb completely surrounding it, and the destructors can be placed on moderately expensive land not available in New York (the Armley destructor at Leeds is, however, somewhat central in position). The rate of interest in Leeds is about three-fourths of what would have to be paid here, and the cost of labor perhaps two-thirds.

Altogether, it seems safe to say that the annual cost per thousand of the population, including all expenses of wear and tear, interest, etc., should not be much, if any, more than double those at Leeds, or $100 00 per one thousand, viz., $150 000 per annum for New York, which leaves a margin for contingencies or profit of from $25 000 to $50 000.

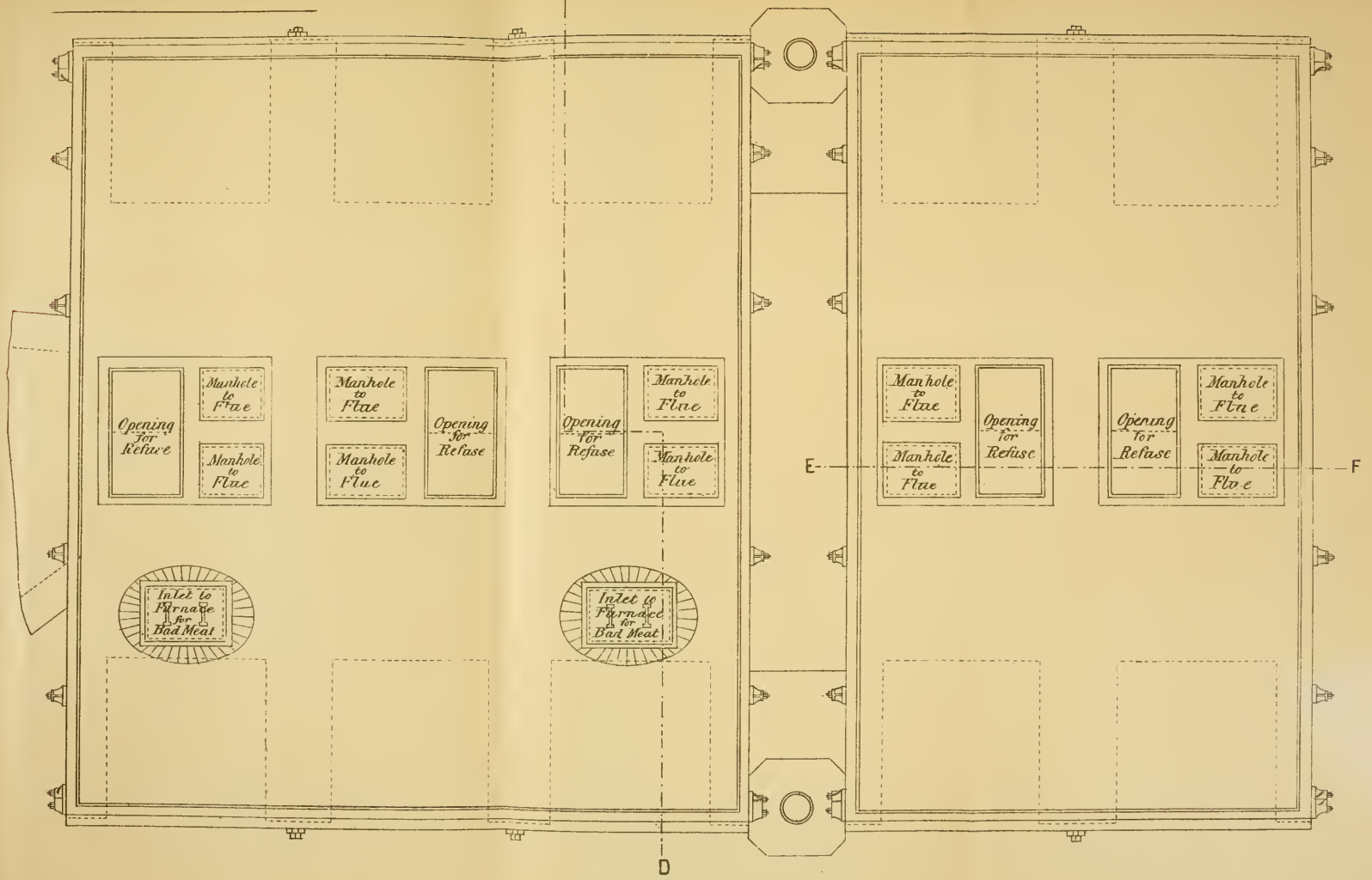
When we have paid this we have absolutely destroyed all injurious elements in the rubbish in the only way which the present state of science indorses as effectual, and we have avoided the nuisance caused by dumping the rubbish into the ocean nearly entirely, the ashes left after burning being a small and innocuous element.

It has been claimed that there is not enough fuel in the rubbish of New York to maintain the necessary fire, but this seems to need proof in view of the English experience. One reason alleged for this is the practice of the poorer population of washing the cinder out of the ashes and reburning it, letting the ashes and the finer cinder go into the sewers. If so, it is time that this practice was stopped by attaching penalties to such washing, and by obliging the owners of tenements to provide dust and ash-spouts, into which the ashes could be sifted instead of into the sewers.

LEEDS CORPORATION
REFUSE DESTRUCTOR, ARMLEY.

PLAN

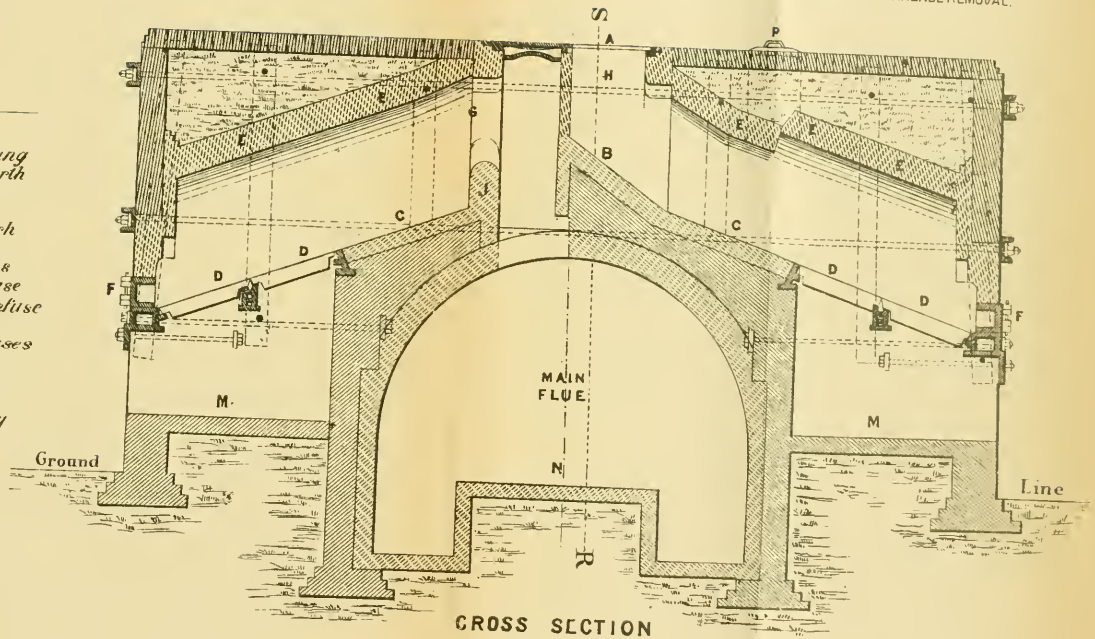
PLATE LXXXVIII
TRANS. AM. SOC. CIV. ENG'RS
VOL. XV. Nº 345
WHITE ON EUROPEAN
SEWAGE AND GARBAGE REMOVAL.



Scale 4 Feet = One Inch

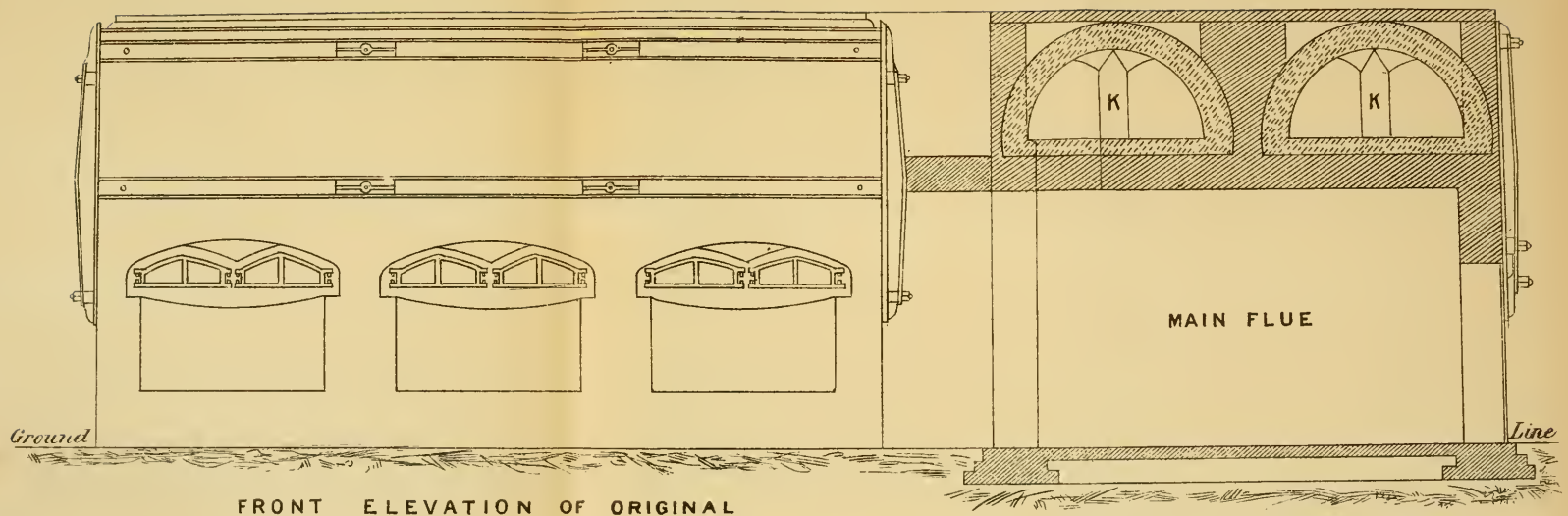
REFERENCE

A Refuse Feed Opening
B Incline above hearth
C Drying Hearth
D Fire Bars
E Reverberatory Arch
F Clinkering Doors
G Opening for Gases
H Opening for Refuse
J Bridge to keep Refuse out of the Flue
K Wall to divide Gases from Refuse
M Ash Pits
N Flue to Chimney
P Mattress Opening



CROSS SECTION
ON LINE C.D.

Scale ¼ Inch = 1 Foot



FRONT ELEVATION OF ORIGINAL THREE PAIRS OF CELLS.

SECTION ON LINE E. F. OF TWO PAIRS OF CELLS SUBSEQUENTLY ERECTED.

Scale 1/4 Inch = 1 Foot.

AMERICAN SOCIETY OF CIVIL ENGINEERS.

INSTITUTED 1852.

TRANSACTIONS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

346.

(Vol. XV.—December, 1886.)

A NOTE ON THE COST OF CONCRETE.

By CAPT. O. E. MICHAELIS, M. Am, Soc. C. E.

READ JANUARY 20TH, 1886.

The Troy Steel and Iron Company's new furnace plant is now erecting upon Breaker Island, situated in the Hudson River not far below Watervliet Arsenal, my present station. The magnitude and scope of this plant may be seen from the following description furnished by Mr. Robert W. Hunt, M. Am. Soc. C. E., General Superintendent of the Company.

THE PLANT.

The entire plant to be located upon Breaker Island will be one of the largest and most complete of its kind known in the history of iron production. The company owns an area of about one hundred acres upon the island. On this land will be constructed three blast furnaces with all requisite appointments. The furnaces themselves will be each of 18 feet diameter of bosh, and 80 feet high. Each furnace will be fitted with four Whitwell fire-brick hot-blast stoves, each 20 feet in diameter and 60 feet in height. The draught stack for the stoves and boilers will be 200 feet high and 12 feet 6 inches in clear diameter. There will be

seven blowing engines with steam cylinders of 42 inches diameter, blowing cylinders of 84 inches diameter and 84 inches stroke. Each engine will discharge at the ordinary working speed 12,000 cubic feet of air per minute, at a pressure of from 10 to 15 pounds. The engines will be built by the Dickson Manufacturing Company, of Scranton, Pa. Steam for the engines will be supplied by sixteen Heine patent safety boilers of 2 400 horse power capacity. These boilers are of recent invention, and are believed to represent the highest effectiveness and economy of service. It is designed that not more than six of the engines shall be in operation simultaneously, the seventh being held in reserve against any contingency that may arise.

Connected with each furnace will be a casting-house, 150 feet long, built of brick, with an iron roof of 50 feet span. The engine-house, which will stand north of the furnaces, will be of brick, 150 feet long by 40 feet wide, and roofed with slate. The boiler-house, adjoining the engine-house, will be 153 feet long by 45 feet wide, of brick with iron roof.

To supply water for the plant, there will be three steam pumps, any two of which will have ample capacity to meet the requirements in this direction, and the same statement will apply to three pumps provided for feeding the boilers. Thus one of each series of pumps will always be held in reserve. The water supply pumps will deliver into an iron water tank standing upon cast-iron columns of thirty feet in height, thus giving a head never less than thirty feet.

There will also be a stock-house, 300 feet long by 100 feet wide, constructed of iron, through which an elevated track will run over pockets into which the material will be dumped from the cars. A substantial dock will be constructed along the river front, 500 feet of which is already under way.

The Foundations.

The work thus far accomplished at Breaker Island, while very great in itself, has been merely preliminary. It consists mainly of building the foundations for the substantial superstructures yet to arise, and for the massive furnaces and their appurtenances necessary to the equipment of the plant. In constructing these foundations, which has been done by the company itself, excavations were made to a bed of gravel overlying slate rock This deposit was found at an average depth of about 15 feet below the surface of the Island. The excavations were

cribbed with timber and filled with concrete to the surface level. The general level of the plant will be 13 feet above the surface of the ground; hence the foundations have been carried to that height. In order to insure the necessary solidity, a superficial wall of stone about 18 inches thick was built up to the required level, and the inclosed space will be filled in with concrete. The hearth level of the furnaces proper will be 6 feet above the general level. The total quantity of concrete used amounts to about 10 000 cubic yards, the largest single mass of which forms the foundations for the Whitwell hot-blast stoves and their draught-stack, the former being 32 feet square and the latter 333 feet long, 27 feet wide, and 33 feet high. Through the center of this mass, and connecting with the draught-stack, is a flue, lined with fire-brick, 310 feet long, 8 feet wide, and 10 feet 6 inches high.

Ground was broken on the Island September 1st, 1885, but it was not until the 20th that the operating force was organized. From that time until December 31st (when the work was discontinued) I had every opportunity of examining the material used as well as to see the methods adopted to insure uniformity and reliabity of result.

The following figures show the amount of work done and material handled within three and one-half months.

There was used for concrete:

Broken stone	7 099½	cubic yards.
Gravel	3 487	"
	10 586½	"

There was added to this:

Fine sharp sand	1 286 cubic yards.
Hydraulic cement	11 832 barrels.

Producing 9 605 cubic yards of concrete.

Cost.

7 099½ cubic yards of broken stone	$9 939 00
4 773 " gravel and sand	1 402 38
11 832 barrels of hydraulic cement	11 832 00
Labor of drawing cement	227 50
" mixing cement	8 153 00
" unloading stone	1 297 03
Four months superintendence	1 000 00
	$33 850 91

Cost of concrete in place, $3 $52\frac{43}{100}$ per cubic yard.

The cement used was from New York and Rosendale Cement Company, N. Y.; F. O. Norton Cement Company, N. Y.; J. H. Ramsey's Hydraulic Cement, Howe's Cave, N. Y.; and Eli Rose, Treasurer, Howe's Cave Cement, N. Y.

From the 11 832 barrels of cement there were tests made daily during the progress of the work, both for fineness and tensile strength—for the former with the 10 000-mesh standard sieve, and for the latter with Fairbanks & Co.'s automatic tester. The following is the record. (See tables appended.)

All the cement used was fresh, having been burned not to exceed ten days before, which may account for the high tensile strength shown by all.

The conditions, both as to cost of material and labor, must be considered exceptionally favorable, the broken stone costing $1 41 per cubic yard at the dock; sand and gravel found on the island in close proximity to the work, and costing but 30 cents per cubic yard; and cement at $1 per barrel at the dock.

The concrete, stone walls and other masonry put in place since September 15th, and up to December 31st, amount to 22 365 net tons.

TESTS, NEW YORK AND ROSENDALE CEMENT COMPANY'S CEMENT.

Fineness.	Hours drying.	Tensile strength per square inch.	Fineness.	Hours drying.	Tensile strength per square inch.
		Pounds.			Pounds.
.957	24	90	.955	24	124
.957	24	102	.940	24	129
.945	24	104	.931	24	122
.951	24	117	.967	24	98
.933	24	115	.935	24	106
.943	24	97	.959	24	125
.951	24	97	.949	24	114
.942	24	91	.931	24	95
.937	24	117	.940	24	123
.944	24	118	.945	24	99
.950	24	109	.933	24	113
.939	24	123	.941	24	145
.947	24	117	.945	24	120
.943	24	95	.951	24	90
.943	24	102	.953	24	95
.947	24	104	.935	24	118
.946	24	109	.955	24	113
.944	24	119	.934	24	107
.943	24	112	.934	24	142
.944	24	108	.937	24	116
.951	24	119	.939	24	104
.952	24	121	.936	24	132
.960	24	114	.953	24	116
.961	24	144	.952	24	112
.953	24	138	.950	24	125
.952	24	131	.949	24	104
.952	24	128	.949	24	110
.983	24	125	.951	24	126
.954	24	140	.948	24	114
.941	24	138	.949	24	119
.942	24	122	.946	24	95
.950	24	127	.940	24	124
.952	24	135	.940	24	100
.954	24	125	.941	24	107
.949	24	121	.940	24	96
.950	24	127	.938	24	101
.970	24	132	.942	24	126
.971	24	128	.941	24	98
.970	24	130	.948	24	101
.962	24	139	.953	24	123
.965	24	129	.955	24	121
.971	24	137	.956	24	121
.972	24	124	.946	24	90
.968	24	118	.953	24	143
.957	24	133	.947	24	97
.964	24	120	.937	24	90
.965	24	113	.938	24	98
.945	24	103	.939	36	117
.961	24	114	.910	36	107
.960	24	119	.940	36	115

TESTS, NEW YORK AND ROSENDALE CEMENT COMPANY'S CEMENT.—(*Continued.*)

Fineness.	Hours drying.	Tensile strength per square inch.	Fineness.	Hours drying.	Tensile strength per square inch.
		Pounds.			Pounds.
.948	36	121	.964	48	123
.953	36	112	.914	48	118
.952	36	118	.931	48	116
.952	36	116	.942	48	130
.960	48	178	.920	48	105
.948	48	174	.943	48	137
.948	48	141	.950	48	139
.953	48	159	.960	48	170
.953	48	174	.951	48	150
.943	48	126	.944	48	106
.951	48	115	.950	48	124
.959	48	119			

TESTS, F. O. NORTON'S CEMENT.

Fineness.	Hours drying.	Tensile strength per square inch.	Fineness.	Hours drying.	Tensile strength per square inch.
		Pounds.			Pounds.
.921	24	109	.940	24	118
.900	24	127	.935	24	117
.911	24	119	.935	24	120
.910	24	123	.936	24	119
.913	24	117	.936	24	124
.919	24	103	.928	24	88
.938	24	101	.929	24	102
.939	24	126	.930	24	106
.937	24	142	.928	24	127
.934	24	119	.931	24	98
.937	24	117	.932	24	106
.935	24	111	.930	24	111
.932	24	124	.938	24	101
.932	24	118	.938	24	118
.936	24	123	.950	24	126
.937	24	141	.950	24	115
.939	24	137	.925	24	121
.919	24	126	.926	24	134
.961	24	130	.933	24	120
.943	24	110	.934	24	125
.951	24	137	.933	24	127
.949	24	105	.933	24	143
.921	24	88	.935	24	113
.918	24	121	.934	24	129
.941	24	99	.936	24	134

TESTS, F. O. NORTON'S CEMENT—(*Continued.*)

Fineness.	Hours drying.	Tensile strength per square inch.	Fineness.	Hours drying.	Tensile strength per square inch.
		Pounds.			Pounds.
.941	24	128	.930	24	97
.935	24	124	.938	24	101
.948	24	136	.924	24	122
.947	24	126	.931	24	96
.948	24	130	.934	24	....
.953	24	126	.934	24	....
.953	24	134	.933	24	....
.947	24	135	.932	24	....
.956	24	134	.935	24	....
.961	24	122	.930	24	107
.949	24	134	.932	24	128
.953	24	134	.922	24	116
.960	24	130	.922	24	112
.957	24	132	.934	48	128
.952	24	129	.934	48	150
.957	24	127	.932	48	146
.955	24	125	.932	48	122
.960	24	124	.932	48	121
.960	24	147	.950	48	163
.951	24	125	.950	48	159
.937	24	131	.952	48	161
.929	24	141	.947	48	168
.947	24	130	.945	48	166
.937	24	104	.926	48	133
.931	24	100	.931	48	130
.919	24	115	.959	48	124
.900	24	116	.920	48	125
.921	24	106	.930	48	127
.915	24	148	.938	48	129
.930	24	113	.945	48	160
.902	24	101	.932	62	135
.941	24	91	.926	62	119
.938	24	108	.927	62	117
.950	24	115	.921	62	133
.951	24	113	.920	62	137
.937	24	123	.932	62	115
.943	24	122	.930	62	127
.930	24	129	.927	62	130
.932	24	126	.931	62	133
.932	24	119	.920	62	119
.922	24	129	.946	192	210
.923	24	127	.951	192	214
.922	24	128	.953	192	216
.931	24	122	.960	192	221
.928	24	92	.941	192	209
.927	24	125	.938	192	208
.931	24	131	.957	192	221
.928	24	146	.961	192	219
.928	24	111	.949	192	217
.931	24	118	.952	192	219

TESTS, J. H. RAMSEY'S HOWE'S CAVE CEMENT.

Fineness.	Hours drying.	Tensile strength per square inch.	Fineness.	Hours drying.	Tensile strength per square inch.
		Pounds.			Pounds.
.932	24	153	.945	24	119
.935	24	127	.943	24	133
.930	24	140	.949	24	116
.934	24	140	.946	24	128
.934	24	157	.946	24	116
.933	24	135	.925	24	109
.935	24	144	.926	24	100
.944	24	125	.925	24	103
.934	24	127	.928	24	112
.952	24	121	.928	24	111
.944	24	124	.949	24	117
.920	24	113	.948	24	117
.900	24	105	.954	24	119
.880	24	109	.950	24	122
.870	24	102	.952	26	121
.880	24	109	.972	26	134
.939	24	112	.970	26	140
.939	24	112	.980	26	130
.944	24	107	.927	26	130
.939	24	120	.928	26	144
.942	24	117	.928	26	140
.966	24	116	.939	26	146
.963	24	118	.889	26	132
.964	24	124	.901	26	136
.964	24	121	.902	26	132
.965	24	155	.906	26	130
.933	24	130	.899	26	130
.939	24	119	.900	26	132
.940	24	124	.981	26	133
.939	24	101	.967	26	110
.940	24	116	.968	26	127
.929	24	108	.971	26	127
.930	24	113	.971	26	140
.939	24	104	.963	26	106
.931	24	124	.958	26	117
.931	24	113	.965	26	116
.959	24	124	.961	26	117
.962	24	113	.960	26	116
.963	24	120	.971	20	102
.961	24	117	.969	24	147
.960	24	113	.987	24	177
.923	24	115	.949	24	126
.923	24	107	.961	24	165
.934	24	113	.961	24	159
.923	24	104	.968	24	131
.928	24	116	.970	24	152
.924	24	101	.968	24	156
.914	24	107	.975	24	139
.913	24	112	.987	24	119
.913	24	102	.990	24	168
.914	24	143	.997	24	173

TESTS, J. H. RAMSEY'S HOWE'S CAVE CEMENT—(*Continued*).

Fineness.	Hours drying.	Tensile strength per square inch,	Fineness.	Hours drying.	Tensile strength per square inch.
		Pounds.			Pounds.
.996	24	116	.946	24	141
.959	24	124	.919	24	135
.980	24	184	.896	24	131
.990	24	162	.901	24	146
.945	24	155	.902	24	146
.985	24	150	.889	24	121
.982	24	145	.896	24	132
.973	24	127	.965	24	127
.979	24	170	.950	24	99
.987	24	145	.956	24	125
.973	24	138	.952	24	124
.986	24	117	.954	24	129
.971	24	170	.916	24	131
.973	24	139	.914	24	132
.952	24	132	.920	24	132
.960	24	146	.916	24	144
.952	24	148	.919	24	146
.985	24	145	.955	24	132
.990	24	145	.950	24	133
.987	24	164	.957	24	143
.990	24	141	.955	24	146
.982	24	143	.957	24	149
.978	24	138	.919	24	143
.979	24	182	.919	24	124
.992	24	132	.934	24	137
.994	24	168	.965	28	160
.971	24	110	.963	28	177
.998	24	141	.970	28	142
.979	24	139	.967	28	158
.965	24	137	.983	28	131
.980	24	126	.963	28	127
.973	24	138	.971	28	121
.977	24	103	.981	40	139
.981	24	138	.965	40	121
.982	24	146	.938	40	145
.969	24	155	.941	40	120
.967	24	143	.955	40	117
.980	24	132	.927	40	123
.967	24	120	.951	40	137
.935	24	181	.953	48	149
.979	24	159	.948	48	136
.977	24	146	.957	48	150
.974	24	130	.949	48	165
.974	24	180	.936	48	179
.973	24	192	.978	48	152
.974	24	179	.948	48	157
.974	24	175	.953	48	141
.972	24	186	.907	48	142
.942	24	141	.906	48	143
.948	24	150	.906	48	135
.954	24	140	.903	48	152
.946	24	147	.906	48	129

TESTS, J. H. RAMSEY'S HOWE'S CAVE CEMENT—(*Continued*).

Fineness.	Hours drying.	Tensile strength per square inch.	Fineness.	Hours drying.	Tensile strength per square inch.
		Pounds.			Pounds.
.964	48	190	.900	48	134
.970	48	197	.961	62	200
.966	48	161	.957	62	200
.985	48	154	.956	62	157
.962	48	149	.957	62	190
.977	48	176	.951	62	199
.987	48	171	.955	62	121
.944	48	147	.947	62	134
.942	48	132	.959	62	170
.938	48	142	.987	62	126
.946	48	150	.991	62	148
.946	48	147	.974	62	150
.965	48	112	.969	62	167
.967	48	102	.966	62	150
.970	48	102	.960	62	162
.963	48	104	.944	62	142
.966	48	111	.947	62	145
.898	48	142	.948	62	159
.897	48	145	.946	62	145
.903	48	122	.947	62	142
.902	48	131			

TESTS, ELI ROSE, TREASURER, HOWE'S CAVE CEMENT.

Fineness.	Hours drying.	Tensile strength per square inch.	Fineness.	Hours drying.	Tensile strength per square inch.
		Pounds.			Pounds.
.917	24	104	.852	24	135
.920	24	104	.825	24	137
.922	24	102	.830	24	120
.921	24	106	.835	24	147
.926	24	101	.819	24	150
.978	24	107	.829	24	150
.974	24	102	.824	24	151
.978	24	100	.822	24	153
.976	24	112	.792	24	160
.975	24	101	.794	24	154
.941	24	111	.804	24	150
.918	24	149	.806	24	145
.939	24	137	.796	24	146
.843	24	134	.880	24	131
.847	24	123	.882	24	161

TESTS, ELI ROSE, TREASURER, HOWE'S CAVE CEMENT—(*Continued*).

Fineness.	Hours drying.	Tensile strength per square inch.	Fineness.	Hours drying.	Tensile strength per square inch.
		Pounds.			Pounds.
.883	24	123	.853	24	93
.882	24	132	.843	24	98
.881	24	169	.855	24	96
.873	24	144	.890	24	98
.900	24	120	.879	24	99
.900	24	112	.889	24	138
.906	24	118	.888	24	138
.900	24	126	.888	24	129
.895	24	124	.905	24	144
.862	24	125	.892	24	133
.868	24	147	.893	24	103
.863	24	168	.906	24	118
.862	24	153	.918	24	137
.866	24	146	.911	24	139
.939	24	149	.919	24	140
.901	24	139	.911	24	138
.943	24	108	.876	24	107
.941	24	151	.871	24	122
.943	24	158	.877	24	124
.922	24	132	.853	24	131
.894	24	137	.870	24	124
.921	24	134	.960	24	120
.905	24	140	.957	24	115
.910	24	124	.954	24	124
.921	24	149	.957	24	120
.926	24	135	.941	24	114
.920	24	155	.916	24	128
.921	24	150	.872	24	136
.918	24	160	.875	24	134
.937	24	159	.806	24	145
.934	24	114	.900	24	136
.941	24	119	.958	24	114
.940	24	105	.963	24	104
.935	24	107	.960	24	119
.891	24	116	.962	24	117
.896	24	147	.961	24	117
.894	24	142	.914	48	125
.892	24	176	.915	48	123
.844	24	182	.900	48	123
.840	24	146	.895	48	121
.842	24	119	.945	48	119
.838	24	114	.938	48	123
.820	24	112	.933	48	137
.735	24	115	.932	48	134
.739	24	118	.940	48	119
.763	24	112	.929	48	123
.746	24	102	.900	48	163
.755	24	108	.909	48	171
.853	24	120	.907	48	157
.863	24	109	.900	48	157

TESTS, ELI ROSE, TREASURER, HOWE'S CAVE CEMENT—(*Continued.*)

Fineness.	Hours drying.	Tensile strength per square inch.	Fineness.	Hours drying.	Tensile strength per square inch.
		Pounds.			Pounds.
.904	48	118	.855	69	154
.882	48	151	.898	92	174
.895	48	151	.900	116	179
.883	48	149	.901	140	163
.890	48	125	.901	164	174
.905	68	133	.900	212	209
.852	69	174	.904	236	207
.882	69	163	.899	260	251
.878	69	150	.900	284	270
.885	69	151	.901	308	340

At the meeting of the Society, May 19th, 1886, questions were asked by Members as to the condition of this large monolithic mass of concrete six months after its construction; as to the high tensile strength of the cement in twenty-four hours; as to the cost of the concrete in days' work; and as to the low cost of this construction. The author of the paper replies in the following note:

I will try to answer the questions *seriatim.* The past winter was very severe; upon the breaking up of the ice above we had higher water than ever before, except in the famous 1857 freshet. The concrete mass, subjected to the action of ice and water, stood intact. Here and there I detected some slight faults, which were excised, and probably in measure did not amount to more than a barrel. No cracks or settling have been observed, and the work of building is now going on rapidly.

The parties who furnished the cement, all named in the paper, would doubtless gladly supply any quantity ordered. The question as to cost in days' work is met by the facts given, 11 832 barrels of cement, and $1 per day for all labor, except superintendence. I again must invite attention to the favorable conditions under which this work was done. The main plant was shut down and out of blast; the employees gladly accepted this job at $1 per diem. They felt they were working for their future good, and, animated by a genuine *esprit de corps*, they wrought with a will, and accomplished much.

AMERICAN SOCIETY OF CIVIL ENGINEERS.

INSTITUTED 1852.

TRANSACTIONS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

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(Vol. XV.—December, 1886.)

THE WATER-WORKS OF SOUTHINGTON, CONNECTICUT.

BY THEODORE H. MCKENZIE, M. Am. Soc. C. E.

READ FEBRUARY 3D, 1886.

The town of Southington, in Hartford County, Connecticut, is the seat of several large manufacturing establishments. It is on the Quinnipiac River, in a valley surrounded by hills rising 600 feet above the level of the stream.

Works for supplying water for domestic use and fire protection were constructed by a private corporation, "The Southington Water Company," in 1883-84, after the plans and under the direction of the writer. The water is procured from Humiston's Brook, a mountain stream having a drainage area of two and one-half square miles, mostly uncultivated, rocky land, with very irregular surface. The rock is granite. The water is impounded by an earth dam about four miles from Southington Centre and 530 feet above its level. Another distributing reservoir is built three-fourths of a mile nearer the town and 242 feet above it, from which a cast iron-pipe is laid to the town.

The gaugings of the stream, taken at the distributing reservoir during the year 1883, showed an average daily flow of 4 300 000 gallons. The gathering ground is particularly favorable to the preservation of

the purity of the water on account of the freedom from swamps and the sparse population, there being but three houses within the entire area.

Storage Reservoir.

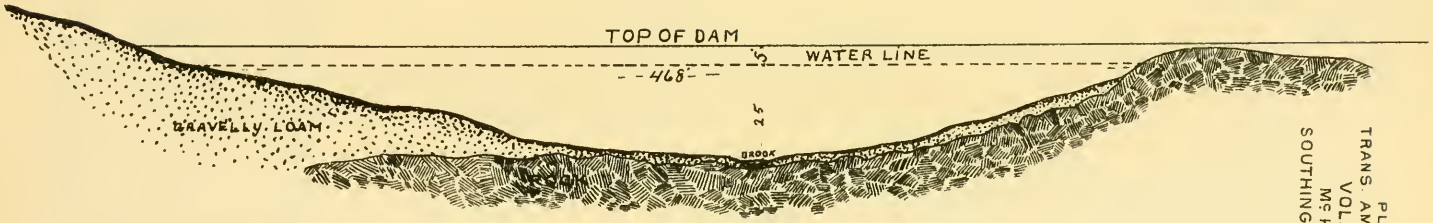
The storage reservoir covers an area of 23 acres, with 25 feet in depth of water at the dam, and has a capacity of 60 000 000 gallons. The valley in which this reservoir lies is of such form that nearly the entire area is covered with deep water, the sides being quite abrupt. The bed is of rock and gravelly soil; the ground was thoroughly cleared of all wood and vegetable growth, and burned over.

Storage Reservoir Dam.

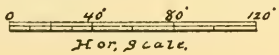
The dam is mostly of earth. It is 520 feet long, 16 feet wide on the top, and 30 feet high, with stone masonry and puddle heart wall and dry stone slope wall. The water slope is two to one, and the outer slope one and one-half to one. (Plates XCI and XCII.)

The surface soil was entirely removed from the site of the dam for a depth of two feet or more, and wherever the bed rock lay within four feet of the surface the earth overlying it was entirely removed. The bed rock was reached for about two-thirds of the length of the dam. Where it was not reached a center trench 10 feet wide was excavated for a depth of about four feet below the average bed of the dam, and a cemented stone masonry wall 4 feet thick was built in the center of the trench and carried to an average height of 5 feet for nearly the entire length of the dam. The surface of the rock under the wall was washed clean in order that the cement might properly unite with the rock.

On each side of the masonry wall, and for the entire height and length of the dam, a puddle wall was built, 10 feet in thickness at the bottom and 6 feet at the top. It was carried up simultaneously with the rest of the dam, and was composed of one part clean, sharp sand and two parts loam, which was thoroughly mixed and wet and then worked with spades in 6-inch layers. The earth for the remainder of the dam was carefully selected loam free from turf, roots or stones, and was put on in horizontal layers of not more than six inches in depth, each layer being thoroughly wet and rolled compact with a 3-ton grooved iron roller. The excavated material was put in a waste bank at the foot of the lower slope, and will form a part of the dam in the event of its being raised.



PROFILE ON LINE OF STORAGE RESERVOIR DAM



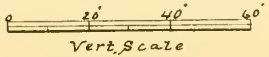


PLATE XCI.
TRANS. AM. SOC. CIV. ENG'RS
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McKENZIE ON
SOUTHINGTON WATER WORKS.

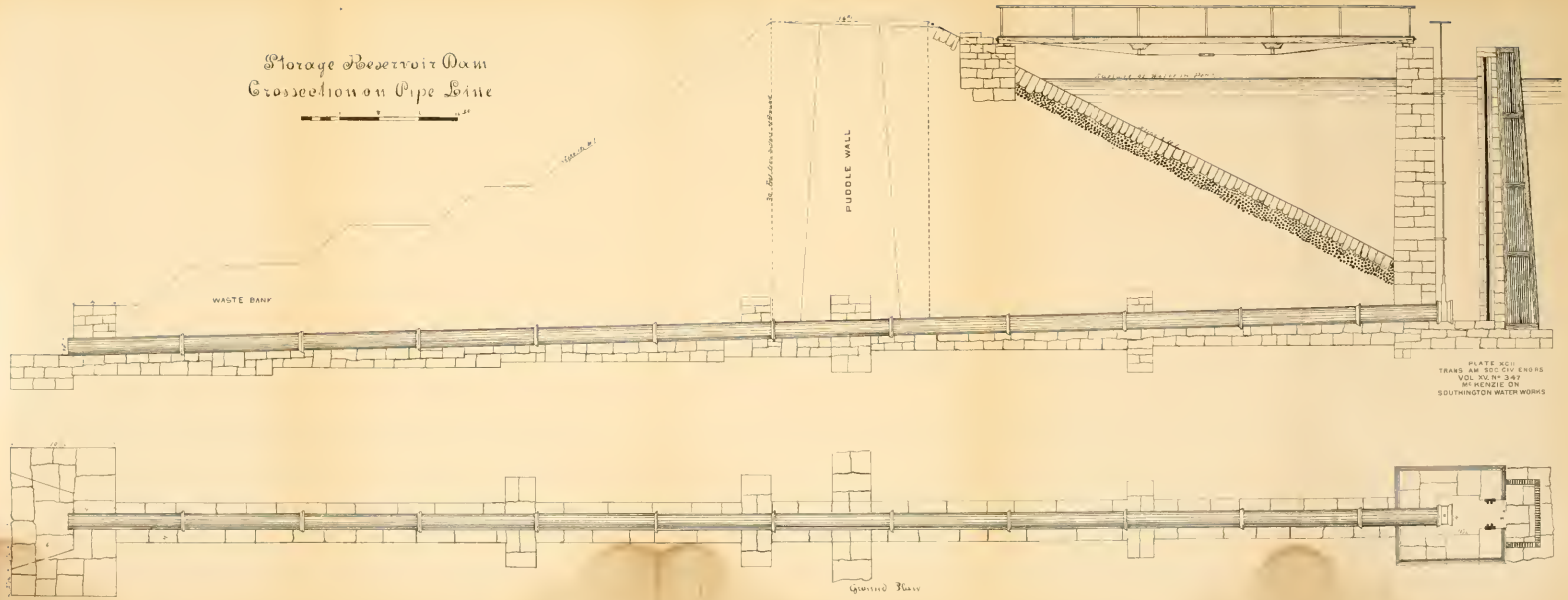

PLATE XCII
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The water slope of the dam was covered 18 inches in depth with small broken stone, over which was laid a paving of large stone 15 inches in depth.

The top of the dam is 5 feet above the bed of the overflow.

A 20-inch cast-iron pipe is laid through the dam on a heavy masonry wall for its entire length, with short cut-off walls every 24 feet to break the continuity of the surface and prevent the water following the pipe through the dam. The masonry under the pipe, and also the wing walls at the outlet are founded on the bed rock. The pipe is 144 feet in length, and terminates at the upper end in a 20-inch stop-cock set in a square chamber with side walls of masonry extending the full height of the dam. On the side toward the reservoir an opening is left two feet wide and faced with grooved iron castings in which gates of 3-inch white oak plank (made in sections) are fitted to slide, so that the water can be entirely shut out or drawn from any depth desired.

An overflow or wasteway, 28 feet in width at the bottom, was excavated through the solid rock at the east end of the dam, through which the water is conducted back to the channel of the brook below the dam.

The materials moved in the construction of the dam were as follows:

Excavation on the site of the dam and overflow, and clearing to obtain suitable filling material for the dam.....	4 600	cubic yards.
Loose and solid rock excavated.....	237	"
Earth filling in the dam.....	19 000	"
Masonry in walls and foundations.....	375	"
Masonry in well chambers.....	89	"
Slope paving.....	1 300	"

The dam was built by contract, the company keeping an inspector on the work,

The water from the storage reservoir follows the original channel of the brook for a distance of three-fourths of a mile and is aerated by flowing over the rocky and precipitous bed, and much better fitted for use than if taken directly into the pipes from the storage reservoir.

Distributing Reservoir.

The distributing reservoir is formed by erecting a masonry dam 20 feet in height from the bed of the stream to the overflow, and, when full, covers an area of one and one half acres and contains three million gallons. The bed of the reservoir was cleared of all wood and vegetable growth and burned over, and the woods surrounding the reservoir

cleared off 30 feet or more outside the flow line. The dam is 170 feet long on the top, 14 feet thick at the base, and 5 feet thick at the overflow, 20 feet above the base. The remainder of the dam is carried 3 feet higher, and is 4 feet thick at the top. (Plates XCIII and XCIV.)

The bed of the stream was a quicksand, which lay very firmly in its natural bed. The foundation was prepared by excavating two trenches parallel with the face of the dam to a depth of about three feet. Sills were laid at the bottom and top of the excavation and sheet piling driven and spiked to the sills; the trenches were then filled with concrete, and a layer of concrete 1 foot thick by 15 feet wide covers the entire surface under the dam. The dam is built of granite rubble masonry. The stone was quarried within 1 000 feet of the dam. Every stone was cleaned and wet before laying, and was laid in a full bed of cement-mortar; all interstices were filled with mortar and stone driven into it.

Well-chamber and Gate-house.

The dam forms the lower side of the well chamber, which is 6 by 8 feet in the clear inside, and is built of the same class of masonry as the dam. The walls are three and a half feet thick at the base and two feet thick at the top, lined with a brick wall eight inches thick. A 4-inch space between the brick and stone is filled with pure cement-mortar. There are two inlets from the reservoir to the well. The upper one is operated by a sliding plank gate and draws water from the surface and to a depth of five feet. The lower inlet is through a pipe and culvert extending to the foot of the slope. This inlet draws the water to a depth of twelve feet below the surface of the water, thus giving the advantage of drawing from any depth as the season of the year or the varying condition of the stream may indicate.

A 12-inch waste pipe extends through the dam and well-chamber and draws water to a depth of sixteen feet below the surface. By closing all the inlets to the well and opening a 6-inch waste gate at the bottom, it can be entirely emptied in five minutes and the well cleaned without interfering with the supply, as the water in the main pipe will furnish a supply for the short time required for any ordinary work within the well.

The water, before entering the well, passes through an iron rack or screen covering the inlets to the well, the rods of which are 2 x ½ inch iron and set one inch apart. Within the well the water passes through

two sets of copper wire screens of half and quarter-inch meshes. The screens are set in a cross wall in the center of the well with an opening three feet wide for the whole depth. On the jambs of the opening is anchored a cast-iron frame with grooves lined with Babbitt metal in which the screens slide, and are easily raised by a rope and pulley overhead for the purpose of cleaning. The inlet and outlet pipes are regulated by means of stop-cocks with iron rods extending three feet above the floor of the gate-house, and are operated by brake wheels eighteen inches in diameter. A brick gate-house 11 by 13 feet covers the well. The foundations of the dam are protected from wash under the overflow by a paving of large stone, 3 feet in depth, 50 feet in length and 20 feet wide from the front of the dam. On the top of this is laid a timber and plank apron 10 feet wide for the length of the overflow 40 feet.

The filling back of the dam is of selected materials, free from turf, roots or stones; it was put on in level courses and puddled against the back of the dam; the slope is two to one on the water side.

The materials moved in the construction of the dam were as follows:

Earth exacavtion	750	cubic yards.
Loose and solid rock excavation	76	"
Earth filling back of the dam	1 419	"
Masonry laid in cement	1 021	"
Bank wall and paving	110	"
Concrete in foundations	86	"
Bricks in well and gate-house	17 000	
Timber in apron and sheet filling	4 500	feet.

The work was done by contract. Work was begun on both dams July 1st, 1883, and completed October 1st, 1884; work was discontinued during freezing weather.

Main Supply Pipe.

The main supply pipe through the dam is 12 inches in diameter, and from the dam to the Plantsville Railroad crossing it is 10 inches in diameter; the general depth of the bottom of the pipe is five and one-half feet. The pipe is all accurately laid to a grade with very few horizontal bends, and no curves with a less radius than thirty feet; there are no vertical bends, except at the four summits in the grade, where air-valves are placed to relieve the pipes of any accumulation of air. Blow-offs are placed at each depression in the grade. (Plate XCV.)

The pipe is laid over the river on permanent iron bridges, as in the event of any accident or leakage they are more easily accessible for repairs. The pipes over the bridges are covered with asbestos and felt covered with pitch to protect it from the weather.

The thickness and weights of pipes are adjusted to the pressure due to each one hundred feet of head, according to the following schedule.

SCHEDULE OF CAST-IRON WATER-PIPE TO BE FURNISHED.

Class.	Diameter in inches.	Thickness in decimals of an inch.	Number of pieces.	Stand'd weight in pounds of each piece.	Gross weight in tons.
A	12	.520	16	828	6
A	10	0.489	160	659	47
B	10	0.549	657	742	217
C	10	0.579	223	786	78
C	8	0.522	703	572	180
C	6	0.466	1 275	386	220
C	4	0.409	10 000	232	103
C	.....	.....	Special castings	.....	10
			Total tons	.....	861

All pipes were coated by the ordinary process of immersion in a bath of coal-tar pitch properly heated, and were tested to a pressure of 300 pounds per square inch; the hubs of 10 and 8-inch pipe were 4 inches deep, and for 6 and 4-inch pipe 3½ inches deep, with not less than $\frac{31}{100}$-inch joint room. A groove or recess was cast on the inner surface of the hub, and a bead on the spigot end.

DISTRIBUTION.

From the end of the 10-inch main at Plantsville Railroad crossing, the water is conveyed to Southington Centre by two lines of 8 and 6-inch pipe, and by branch lines of 6 and 4-inch pipe, quite generally distributed about the thickly settled portions of the town, as shown by the accompanying map. (Plate XCVI.)

In some streets and lanes wrought iron-pipe was used to supply tenements, which were protected from fire by hydrants on other streets. Branches were set at the intersection of nearly all the streets for future extension, and gates located at convenient points to shut off and control the water, and avoid the necessity of cutting off a large territory in case of a break.

Blow-offs are located at the crossings of all streams and at other low points in the grade.

There are some extensions of 4-inch pipe yet to be made to complete the original plan and give a good circulation.

The distribution pipes are all laid to a grade, and all summits in the grades arranged so that a house-service pipe acts as an air vent.

Profiles were made and grades adopted on all streets where pipe was laid.

A record was preserved of the location of every gate, both on the mains and house service, so that they can be readily found when the ground is covered with snow.

The entire amount of pipe laid by the company, not including house-service pipe, is $11\frac{55}{100}$ miles.

Hydrants are set at all street intersections, and on long streets usually not more than 500 feet apart; the total number set to date is 69.

The pressure over most of the town is from 90 to 100 pounds to the square inch.

The capacity of the works is such that they will supply five or six fire streams on any of the manufacturing property of the town without seriously affecting the pressure.

The quality and purity of the water is all that could be desired.

The total cost of the works to date is $88 753. The cost is divided about as follows:

Storage reservoir, land, dam, pipes, etc.....	$17 500
Distributing reservoir, land, dam, pipes, etc.....	8 500
Mains and distribution pipes, hydrants, gates, etc.	52 753
Engineering and superintendence.....	5 500
Paid mill-owners for water rights.....	4 500
	$88 753

In the designing and management of the work, the writer was aided by the advice of Mr. J. J. R. Croes, M. Am. Soc. C. E., as consulting engineer, and in the field work and supervision of construction by John M. McKenzie, C.E.

The fact that no leaks have appeared and no failure of any kind occurred in the dams, pipes or fixtures, would seem to indicate that the works were well constructed, and at a very moderate cost as compared with other similar works.

The water of deep reservoirs (particularly new ones), if drawn from the bottom, is often foul and unfit for use, and for that reason the wells at both reservoirs are so arranged as to draw water from the most desirable levels.

The stop-cocks at both dams are located on the upper side of the dams, relieving the pipes under the dams from pressure which would produce the most disastrous results in the event of the smallest leakage under an earth dam.

The pipes and dams are built with a large factor of safety. The lead joints were of more than ordinary depth and thickness; every joint was shoved home to the shoulder of the hub and the earth was thoroughly rammed under and around the pipe, and all were laid to such a depth as to preclude the possibility of freezing.

In the construction of many of the water-works for small towns in the New England States, but little attention has been given to the grades of pipes, and in laying pipe the undulations of the ground are followed without relieving the accumulations of air at the summits, and consequently the flow of the water in the pipes is impeded; but the works above described have been constructed with the idea in view that money judiciously expended in engineering, planning and superintending was a good investment, and the results confirm that theory.

Profile of Stone Dam.

Scale

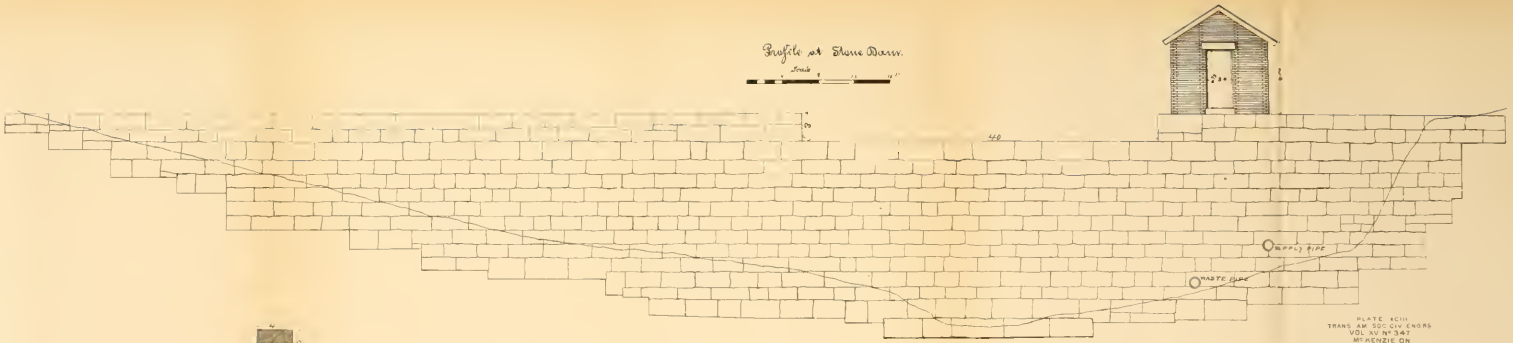
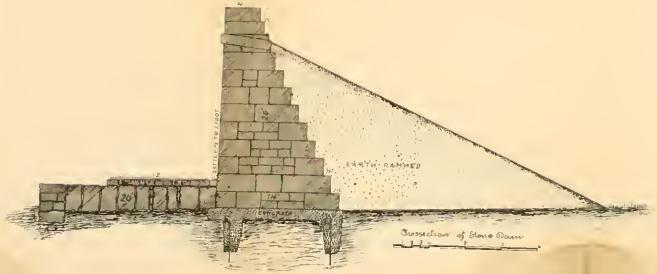
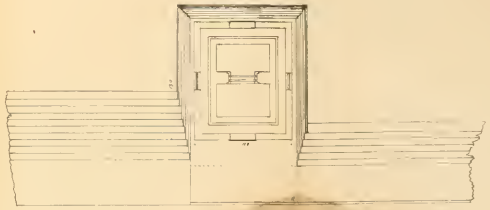


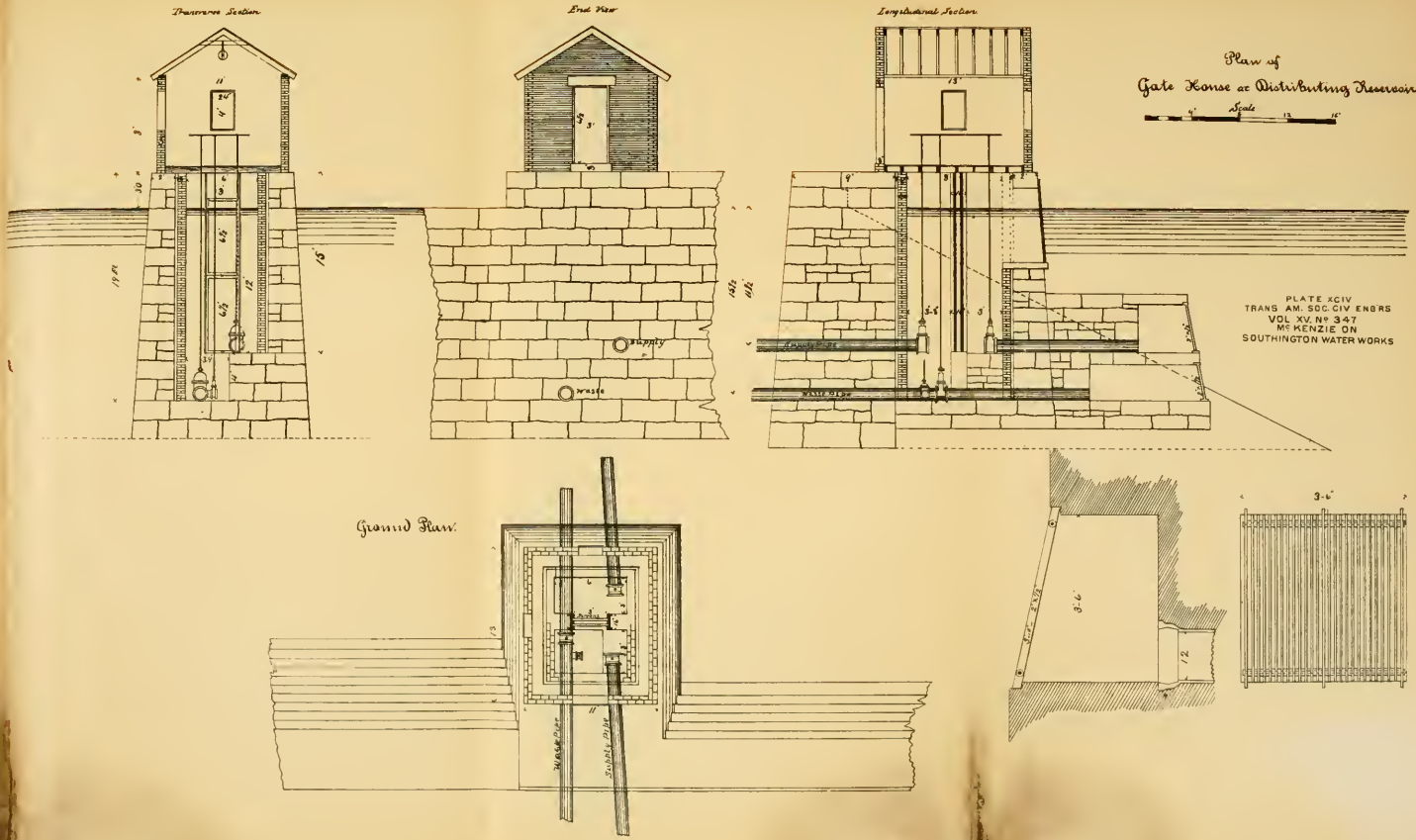
PLATE XCIII
TRANS AM SOC CIV ENGRS
VOL XV No 347
McKENZIE ON
SOUTHINGTON WATER WORKS



Cross section of Stone Dam



Plan of Gate House


Transverse Section
End View
Longitudinal Section
Plan of
Gate House at Distributing Reservoir
Scale
Supply
Waste
Ground Plan
Waste Pipe
Supply Pipe
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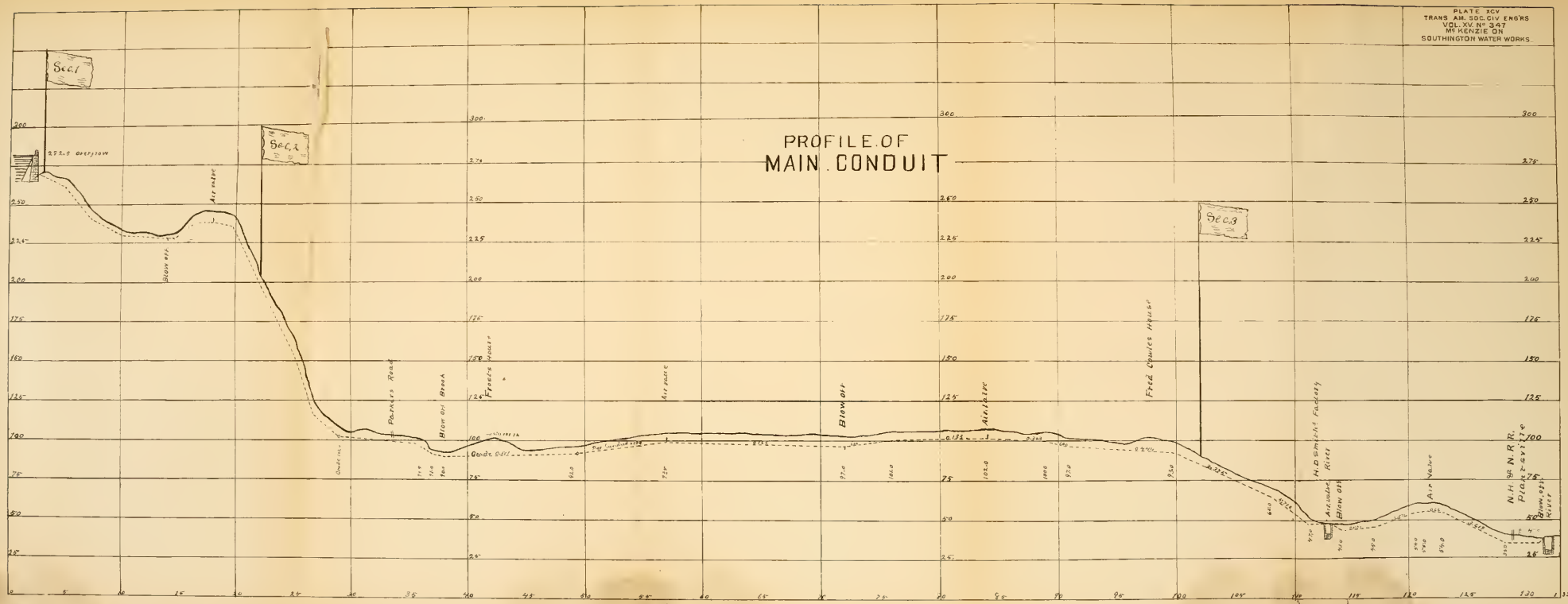
Mc KENZIE ON
SOUTHINGTON WATER WORKS.



AMERICAN SOCIETY OF CIVIL ENGINEERS.
INSTITUTED 1852.

TRANSACTIONS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

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(Vol. XV.—December, 1886.)

ERRORS IN RAILROAD LEVELS.

By HOWARD V. HINCKLEY, M. Am. Soc. C. E.

READ MARCH 3D, 1886.

The "Lists of Elevations" collated by Henry Gannett, M. E., and published in 1877 by the United States Geological Survey, contains, on page 20, a reference to the Atchinson, Topeka and Santa Fé Railroad levels, founded upon statements obtained from that road, and which reads as follows:

"On account of the character of the leveling between Topeka and Kinsley this line is valueless as a check." Corrections of 18 to 68 feet were made by Mr. Gannett upon the elevations furnished from the profiles of different parts of the road. I first noticed this in 1882, and believing that errors of such magnitude in location levels could hardly have been embodied in the construction work without being detected by either leveler or locomotive, I determined to test the correctness of our levels by carefully searching for breaks in datum planes, making the proper corrections for all parts of the line, and obtaining such checks as might be obtainable from intersecting roads and reliable benches in order to determine whether the discrepancies reported were due to the general unreliability of the levels, or to an improper report to the Government

officers of unadjusted levels; and in order to avoid, if possible, a continued confusion and doubt as to elevations of prominent points and, in fact, of nearly every station along the line.

Under authority from A. A. Robinson, M. Am. Soc. C. E., Chief Engineer, and with the very careful assistance of G. A. Lichtenberg, Draughtsman, I proceeded to compile a profile of the entire Atchinson, Topeka and Santa Fé system of roads from the Missouri River to the Gulf of California. This profile was completed January 1st, 1884, and a copy of it placed in the Society's library; it gives the corrected elevation of every station on the system, and the proper corrections to apply to the working or construction profiles for obtaining elevations above sea at any intermediate points. All elevations are in feet and decimals thereof, and are figured for the top of rail at the profile stations indicated in brackets (generally at the east end of depot), and were carried to thousandths—not to indicate that the track has been kept so truly to the original grades, but in order that the results obtained might be correct within themselves to the extent of the information at hand.

The elevations east of the continental divide are above Atlantic "mean tide," and are based upon a United States bench on the face of the south abutment of the Hannibal and St. Joseph Railroad Bridge over the Missouri River at Kansas City. The elevation of this bench was taken as 428.29 (St. Louis directrix, by James T. Gardner in "Elevations of Datum Points," 1875), plus 341.394 (furnished me by William B. Knight, M. Am. Soc. C. E., City Engineer of Kansas City, November 2d, 1882), equals 769.684.

The elevations west of continental divide are above Pacific "mean tide" at Guaymas, Sonora, Mexico, taken 0.625 below Guaymas "mean high tide" (from data furnished by T. J. Seely, M. Am. Soc. C. E., Assistant General Manager Sonora Railway, February 9th, 1883).

The following checks, Nos. 1, 2, 6 and 8, were obtained before the completion of the profile, and the others are the result of later investigation.

Checks.

1. Elevation carried from Kansas City to Atchison, *via* Topeka, compares with elevation taken from United States bench at Atchison, plus 0.006 feet; length of circuit, 173 miles; length of railroad levels, 116 miles.

2. Elevation carried from Kansas City to Emporia Junction compares

with elevation carried from Kansas City *via* Topeka, North Topeka and Junction City over the Union Pacific and Missouri Pacific Railroads to Emporia Junction, plus 0.180; length of circuit 196 miles.

3. Elevation carried from Kansas City, by way of Albuquerque and Atlantic and Pacific Railroad, to the Colorado River compares with Southern Pacific elevation brought from San Francisco (based upon Fort Point high water datum, and corrected, minus 1.790, from data furnished by the observer at San Francisco, October 20th, 1883), minus 2.04; length of railroad levels 2 115 miles.

4. Elevation carried from Kansas City, *via* Albuquerque, Mojave and Yuma, over the Atlantic and Pacific and Southern Pacific to Port Ysabel at the head of the Gulf of California compares with "mean tide" at that point, minus 1.03 (plus 8.90 Southern Pacific reading at Port Ysabel furnished by George E. Gray, M. Am. Soc. C. E., Chief Engineer, minus 2.04; Atlantic and Pacific difference given in check No. 3, minus 1.79; Southern Pacific correction also given in check No. 3); length of railroad levels, 2 149 miles.

5. Elevation at Pueblo crossing of Atchison, Topeka and Santa Fé Railroad, and Denver and Rio Grande Railway, compares with elevation carried from Kansas City to El Moro, thence over Denver and Rio Grande Railway, *via* South Pueblo, minus 0.580; length of railroad circuit, Pueblo, La Junta, El Moro, Pueblo, 246 miles.

NOTE A.—I have no less than six checks (?) upon Pueblo, *via* Denver, covering a range of 26 feet, and the closest result differing more than 15 feet from mine. The indefinite way in which the data for these results have been reported destroys my confidence in their reliability, especially when my El Moro check No. 5 seems to prove the correctness of my Pueblo elevations within six-tenths of a foot. Here I must quote from Gardner's "Elevations" (page 631): "I am satisfied that the important errors in our railroad and canal profiles are not so much due to imperfect instrumental work as to hasty and careless combination of the results." It would also be proper for me to state here that I have checked upon the St. Louis and San Francisco Railroad at Augusta crossing and North Wichita Junction, their elevations being carefully reported by James Dun, M. Am. Soc. C. E., Chief Engineer, and my results comparing with his at these two points, minus 7.212 and minus 7.882 respectively, elevations on both roads being based upon the same elevation of the St. Louis directrix, and these results being therefore independent of the absolute height thereof.

Also, that Mr. Frederick T. Perris, chief engineer of the California Southern, has carefully reported three checks upon the Southern Pacific Railroad as follows:

20. Elevations carried from San Diego over the California Southern Railroad to Waterman by location levels, compare with Southern Pacific elevations from San Francisco, plus 1.801.

21. Elevations carried from San Diego over the California Southern Railroad to Waterman by check levels, compare with Southern Pacific elevations from San Francisco, plus 3.684.

22. Elevations carried from San Diego over the California Southern Railroad to Colton, compare with Southern Pacific elevations from San Francisco, plus 4.058.

These three checks, combined with my check No. 3, would make my elevations, carried over Atlantic and Pacific, check upon the California Southern elevations above referred to, minus 3.841, minus 5.724, and minus 6.098, respectively; or, combining California Southern checks with my check No. 6, carrying my elevations *via* Deming, they would check upon San Diego, minus 1.863, minus 3.746, and minus 4.120 respectively. On the other hand, discarding check No. 20, at Mr. Perris' request, in favor of No. 21, made by check levels, carefully run, and combining my checks No. 6 and No. 8 with California Southern checks No. 21 and No. 22, Guaymas elevations, carried *via* Deming, compare with San Diego elevations, minus 0.356, and minus 0.730 respectively. I am unable to solve this matter satisfactorily at present, but hope to do so at some future time, along with additional checks in Kansas and Colorado, and at Texas and Mexico ports.

6. Elevation at Deming compares with Southern Pacific elevation, corrected as in No. 3, minus 0.062; length of railroad levels, 2 347 miles.

7. Elevation from Deming, carried *via* Southern Pacific and Yuma to Port Ysabel, compares with mean tide at that point (2.80, minus 1.79, minus 0.062), 0.948; length of railroad levels, 1 686 miles.

8. Elevation at continental divide (about 40 miles west of Deming, and upon a stretch of 173 miles of unconstructed line) compares with mean tide elevation brought from Guaymas, minus 3.390; length of railroad levels, 1 657 miles.

9. Elevation at Southern Pacific overhead crossing of the Atchison, Topeka and Santa Fé Railroad, near El Paso, compares with the Southern Pacific elevation at the same point brought from San Francisco, and corrected same as in No. 3, plus 0.128 (from data secured by Southern Pacific Railroad during construction), and plus 0.460 (from data secured by Atchison, Topeka and Santa Fé Railroad four years later).

Note B.—The Atchison, Topeka and Santa Fé determination was merely an approximate second or double check, and the difference between the two checks is due probably to the settling of the overhead trestle. The Southern Pacific check is therefore taken as reliable, and the other discarded.

10. Elevation at Deming compares with elevation carried from Albuquerque over Atlantic and Pacific and Southern Pacific Railroads, *via* Mojave, to Deming (2.04, minus 0.062), plus 1.978; length of circuit, 1 862 miles.

11. Elevation at Rincon compares with elevation carried from Rincon, *via* Deming and El Paso, crossing to Rincon, plus 0.190; length of circuit, 218 miles.

I had thought I should be doing well if I secured a transcontinental check within ten or twenty feet, or if I secured a check upon any reliable bench east of the Rocky Mountains within ten feet. The first check obtained was No. 7, and it was generally considered a remarkable coincidence, if not possibly a "manufactured" check, and I little expected to have it so closely supported by the ten other checks above given. All the old field books and profiles were searched for breaks, and all the checks here given are substantiated by documents on file in my office.

Summarizing first those lines which are all rail, or upon which level checks level, and assuming absolute accuracy in the United States levels between the Kansas City and Atchison benches, we have the following table of

RAIL CIRCUIT CHECKS.

No	From	Via	To	Miles.	Errors in feet.	Errors, feet per mile.
1	Kansas City. ...	Topeka.	Atchison	116	0.006	0.00005
2	Emporia Junc..	North Topeka and Junction City	Emporia Junc..	196	0.180	0.00092
5	Pueblo, ...	La Junta and El Moro.....	Pueblo.....	246	0.580	0.00236
10	Deming.....	Albuquerque and Mojave.	Deming.	1 862	1.978	0.00106
11	Rincon.	Deming and El Paso.	Rincon.....	218	0.190	0.00087

Next summarizing the checks furnished, by the assumption that the mean tide of the two coasts has a common elevation, and that Gardner's Atlantic elevation of Kansas City bench, as above given, is correct (the later levels of the Mississippi River Commission and the Coast Survey to the contrary notwithstanding), and throwing check No. 8 out of the general results, on account of the unreliability of 173 miles of unchecked preliminary mountain location levels, we have the following table of tide checks.

TIDE CHECKS.

No.	From	Via	To	Miles.	Errors in feet.	Errors, feet per mile.
3	Kansas City. . . .	A. and P. R. R.	San Francisco. .	2 115	2.04	0.00096
4	Kansas City. . . .	A. and P. and S. P..	Pt. Ysabel	2 150	1.03	0.00048
6	Kansas City. . . .	Deming.	San Francisco...	2 347	0.062	0.00003
7	Kansas City. . . .	Deming.	Pt. Ysabel.	1 686	0.948	0.00056
8	Kansas City. . . .	Tombstone . . .	Guaymas.	1 657	3.390	. . . . .
9	Kansas City. . . .	El Paso	San Francisco..	2 459	0.128	0.00005

NOTE C.—Gardner, in his elevations of datum points, 1875 (pages 643, 644 and 653), reports errors as follows: 9.9 feet Portland to New Orleans, *via* Chicago, 2 100 miles (0.0048 per mile); 2.44 feet New York Bay to New Orleans, *via* Chicago, 1 800 miles (0.0013 per mile); 4.61 feet Raritan Bay to New Orleans, *via* Chicago, 1 800 miles (0.0025 per mile); 25.0 feet Portland to San Francisco, *via* Chicago, 3 500 miles (0.0071 per mile); 26. feet New Orleans to San Francisco, *via* Kansas City and Denver, 3 200 miles (0.0081 per mile). Mr. S. D. Mason, M. Am. Soc. C. E. Principal Assistant Engineer Northern Pacific, under date of November 19th, 1885, reports an error of "about four feet" (not yet definitely determined) from Lake Superior, at Duluth, Minn., to Commencement Bay, at Tacoma, Wyoming Territory, assuming Lake Superior elevation to be 602 feet—2 033 miles (0.00185 per mile). The correctness of my results, within the limits of my errors, are not corroborated by these errors reported from other roads, as they have no bearing upon the St. Louis directrix or any of my elevations, and are given here merely for a comparison of errors per mile.

By the close results obtained, I am convinced that the necessity for the excessive corrections applied by Mr. Gannett, arose from the elevations reported to him not having been corrected for breaks in datum planes. I do not offer my results as evidence that railroad levels in mountainous regions are generally to be depended on within one one-hundredth of an inch per mile. Nor would I intimate that the close results over these particular circuits and check lines from the Missouri River to the Pacific Ocean prove the correctness (within the limits of my errors) of the elevations of the St. Louis directrix (428.29) and Missouri River benches as established by Mr. Gardner in 1875 from Atlantic tide points. But in view of the fact that the recent levels of the United States Coast and Geodetic Survey and Mississippi River Commission tend to reduce the elevation of the St. Louis directrix thirteen and fifteen feet respectively, the results given in the second table, and based

upon Gardner's St. Louis elevations, are of special interest at this time, for to reduce St. Louis fifteen feet would be to make the "errors in feet" in my second table range from thirteen to nineteen feet.

DISCUSSION.

L. L. WHEELER, M. Am. Soc. C. E.—It may be of interest, in connection with Mr. Hinckley's paper, to give the later determinations of the elevation of St. Louis City Directrix above mean tide.

First.—By levels run under direction of the Mississippi River Commission, from Biloxi, Miss., on the Gulf of Mexico. The value of mean tide depends upon the mean of four lunations in 1882, which may yet receive a small correction. The resulting elevation for St. Louis City Directrix is 412.71 feet.

Second.—By levels run by the United States Coast and Geodetic Survey from Sandy Hook. The resulting elevation is 416.37 feet.

Third.—By levels run by United States Lake Survey to determine the elevations of the Great Lakes, and by levels run by the Mississippi River Commission from St. Louis to Chicago. The resulting elevation is 413.71 feet.

Now it is quite certain that either of the above determinations is entitled to more weight than Gardner's, and that the mean of the three is the best elevation of St. Louis City Directrix above mean tide available. This mean is 414.26 feet. This elevation is 14.03 feet less than the elevation used by Mr. Hinckley in his table of "Tide Checks." His elevation of the bench mark at Kansas City above St. Louis City Directrix should be increased, however, by 0.341 feet, making the total change in the elevation of the bench mark at Kansas City above mean tide 13.69 feet.

If the elevation of the bench mark at Kansas City be increased 13.69 feet, and it is assumed that mean tide of the Atlantic Ocean is at the same elevation as that of the Pacific, then the table of "Tide Checks" would only show large errors.

Edward P. North, M. Am. Soc. C. E.—The discussion of long lines of levels, interesting in themselves and valuable when such care is bestowed on the comparisons, brings an equally interesting question into prominence, viz.: the relative heights of the oceans surrounding our continent. It is asserted, though not yet accepted, that the water in the Gulf of Mexico is higher than on the Atlantic coast, which is swept by the stream originating in the Gulf. Our Pacific coast is swept by the south bound portion of the North Pacific current, early utilized by the Spanish for East India trade, which, starting from about and south of the latitude of Acapulco, flows west to the Philippine Islands northwardly to the coast of Japan, and crosses to this continent as the black current or Kuro Cywa current.

It is to be hoped that either our Coast or Geological Survey will run lines of test levels from one coast to the other, as well as from the Atlantic to the Gulf, so as to determine these heights, for though ordinary railroad test leveling is sufficiently accurate for all constructive purposes, it would not, considering the distance, be satisfactory for the purpose mentioned.

Any levels connecting with points near the head of the Gulf of California should have the mean height of water determined by observations more extended than through a single lunation; as, during about half the year the prevailing winds blow into the mouth of the Gulf, establishing a persistent southward littoral current, it is said, on both shores of the Gulf. During the rest of the year the prevailing winds blow on to the shore nearly at right angles to the direction of the former winds, reversing the littoral currents and sending them to the northward, thus possibly varying the elevation of the water at Guaymas and points north of it.

PROCEEDINGS

OF THE

AMERICAN SOCIETY

OF

CIVIL ENGINEERS.

(INSTITUTED 1852.)

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— January 13, 1886, Financial business transacted; Annual Report adopted, 28.
— January 27, 1886, Standing Committees appointed; Applications considered; Appropriations made, 28.
— February 3, 1886, Twenty-four o'clock system adopted for Society calendars, 28.
— March 10, 1886, Applications considered; Arrangements made for Convention; "Tests of Material" received from Watertown Arsenal; Ordered published, 37.
— March 31, 1886, Applications considered; Financial business transacted, 58.
— April 28, 1886, Applications con-

sidered; Financial business transacted, 58.
— June 9, 1886, Applications considered; Arrangements for Convention made; Meetings of Society ordered suspended during July and August; Appropriations made, 110.
— August 11, 1886, Applications considered; Censors appointed to award the Norman Medal; Committee appointed to award the Rowland Prize; Action taken in regard to resolutions adopted at Convention, 110.
— September 1, 1886, Applications considered; Appropriations made, 110.
— October 6, 1886, Applications considered; Appropriations made, 114.
— November 10, 1886, Applications considered; Appropriations made, 117.
— December 8, 1886, Applications considered; Arrangements for Annual Meeting made; Appropriations made, 124.
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— January 6, 1886, Ballots canvassed; Amendment to By-Laws adopted, substituting word "December" for word "November" in Section 24, Clause 5; "Specifications for the Strength of Iron Bridges," by Joseph M. Wilson, discussed, 1.
— January 20, 1886, Annual Meeting, 2; Annual Reports of Board of Direction, of Treasurer, of Finance Committee, read, 2; Award of Norman Medal, 2; Award of Rowland Prize, 2; Action as to Annual Convention, 3; Report of Committee to confer as to Plan for Library for Joint Use, 3; Report of Committee on Uniform Standard Time, 4; Report of Committee to present subject of Time Nomenclature to Time Conventions, 6; Report of Committee on Compressive Strength of Cements and Compression of Mortars and Settlement of Masonry, 6; Action as to Committee to Consider Changes in Organization of Society, 7; Officers of Society elected, 7; Discussion on Standard Time, 8; Paper by O. E. Michaelis on Cost of Concrete, 8; Appointment of Committee to consider the Relation to Each Other of the Sections of Railway Wheels and Rails, 8; Paper by Thos. Egleston, "Disintegration of the Egyptian Obelisk in Central Park, New York," 8; Description of New Device for Laying Submarine Tunnels by Richard P. Rothwell, 8; Description of Works for Securing Additional Water Supply for the City of New York, by B. S. Church, 8; Visits on January 21st to Croton River, New Croton Aqueduct, Cable Railroad in Tenth Avenue, 8; Reception at Society House 9; Members in attendance, 9.
— February 3, 1886, Ballots canvassed; "Water-works of Southington, Connecticut," by T. H. McKenzie, read, 27.
— February 17, 1886, Deaths of Edward A. Flint and of Louis R. Walton announced; Work done for the Preservation of the Dam at Holyoke, Mass., by Clemens Herschel, read, 27.
— March 3, 1886, Ballots canvassed; Paper on Thermometer Scales by Fred. Brooks, read; Papers on Errors in Railroad Levels, by H. V. Hinckley, read, 37.
— March 17, 1876, Paper on Evaporation, by Desmond Fitzgerald, read; Discussion by George Downe on English and American Railroads Compared, presented, 36.
— April 7, 1886, Ballots canvassed; Amendment to By-Laws adopted in reference to votes for election of officers; Paper on Specifications for Strength of Iron Bridges discussed; Apparatus presented by Henry Faija for testing cement exhibited, 57.
— April 21, 1886, Paper on Ferry Steamer Solano, read; Flattening Ends of Railroad Curves discussed, 58.
— May 5, 1886, Ballots canvassed; Death of Thomas Norton Bailey announced; Report of Committee to present to General Railway Time Convention the subject of

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— May 19, 1886, Death of James D. Burr announced; Errors in Railroad Levels discussed; Note on the Cost of Concrete, by O. E. Michaelis, read, 66.
— June 2, 1886, Ballots canvassed; Paper by Palmer C. Ricketts, Some Constants of Structural Steel, read, 71.
— June 16, 1886, Paper on Water Supply and Sewerage of the Lawrenceville School, by F. S. Odell, read and discussed, 85.
— July 5, 1886, Business meeting during the Annual Convention, 85; Invitation to visit the American Exhibition in London; Report of the Committee on Standard Time, 86; Motion adopted to discharge Committee to consider Changes in Organization of the Society; Committee to consider Plan for Creating Library for Joint Use continued, 87; Committee to Consider Relation to each other of Sections of Railway Wheels and Rails continued; Report of the Committee on Compressive Strength of Cements and Settlement of Masonry, Committee continued, 92; Resolutions adopted in reference to Chairman of Nominating Committee, 95.
— September 1, 1886, Ballots canvassed; Deaths of E. S. Chesbrough and Richard M. Hoe announced: Portrait of James Laurie, first President of the Society presented; Report of Committee on Compression of Cements and Settlement of Masonry discussed; Earthquakes discussed, 109.
— September 15, 1886, paper by John W. Hill, A Masonry Dam, read; Earthquakes discussed, 110.
— October 6, 1886, Ballots canvassed; Paper by Arthur D. Foote, A Water Meter for Irrigation, read; Discussion on Excessive Rainfall, by S. Whinery, read, 113.
— October 20, 1886, Death of George H. Elliott announced; Clamp for Pulling Sheet Piling, by Charles E. Emery, read; Novel Application of the Polar Planimeter, by Charles E. Emery, discussed; Earthquakes discussed, 114.
— November 3, 1886, Ballots canvassed; Paper by Robert L. Harris, on the St. Lawrence Bridge at Lachine, read; drainage of the Valley of Mexico, by Senor Gayol; Gruson type for Land Battery Armor, by A. E. Piorekowski.
— November 17, 1886, Paper by Edward Bates Dorsey, on Irrigation, read, 117.
— December 1, 1886, Ballots canvassed; Death of Walton W. Evans and Martin Coryell announced; Papers on Cement Testing and Freezing of Cement-Mortars discussed; Report of the Committee on Compressive Strength and Settlement of Masonry discussed; Tubes for Electrical Subways described by Edward P. North, 123.
— December 15, 1886, Paper by R. E. McMath on Determination of the Size of Sewers, read; Paper by James B. Francis on Stoppage of Flow in Water Mains by Anchor Ice, 124.
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American Society of Civil Engineers.

PROCEEDINGS.

Vol. XII.—January, 1886.

MINUTES OF MEETINGS.

(Abstract of such as may be of general interest to members.)

OF THE SOCIETY.

JANUARY 6TH, 1886.—The Society met at 20 o'clock, Vice-President George S. Greene, Jr., in the Chair. The ballot was canvassed upon the proposed amendment to the By-Laws, substituting in Section 24, Clause 5, the word "December" for the word "November." The clause will then read:

5th. "Any five Members, not officers of the Society, may present to the Board of Direction, on or before December 1st, a list of names proposed by them for officers, which list or lists shall also be issued for ballot."

There were in the affirmative 142 votes, and in the negative 4 votes. This amendment was declared adopted.

The following candidates were elected. As Members: Maximilian Ferdinand Bonzano, of Philadelphia, Pa.; Franklin Ide Fuller, of Portland, Oregon; George Watson Kittredge, of Zanesville, Ohio; Henry Wadsworth Reed, of Waycross, Ga.; Henry Frederic Rudloff, of Caracas, Venezuela, South America; Albert John Scherzer, Sonsonate, Salvador, Central America. As Associate: Calvin Tomkins, of New York City. As Junior: Harry Lee Van Zile, of Troy, N. Y.

The paper previously presented by Mr. JOSEPH M. WILSON, M. Am. Soc. C. E., on Specifications for Strength of Iron Bridges, was then discussed. Written discussions were presented from Messrs. William H. Burr, Mansfield Merriman, S. W. Robinson, Geo. F. Swain, G. Bouscaren, Mace Moulton, A. P. Boller, Geo. H. Pegram, William Sellers, James G. Dagron, George L. Vose, J. B. Davis and E. Thacher. The paper was also discussed by Mr. C. C. Schneider.

THE ANNUAL MEETING OF THE SOCIETY.

JANUARY 20TH, 1886.—The meeting was called to order by President Graff at 10 o'clock. Messrs. Chas. H. Swan, J. F. Flagg, Robert Cartwright and F. C. Prindle were appointed tellers to canvass the ballot for officers.

The Annual Report of the Board of Direction* was read by the Secretary, and, on motion, accepted.

The Annual Report of the Treasurer* was read by the Treasurer, and, on motion, accepted.

The Report of the Finance Committee* was read by the Secretary, and, on motion, accepted.

The Report of the Board of Censors to Award the Norman Medal was read and accepted. It is as follows:

To the American Society of Civil Engineers:

The Board of Censors to award the Norman Medal for the year terminating August 1st, 1885, report that, in their judgment, the award be made to Paper No. 300, "Record of Tests of Cement Made for the Boston Main Drainage Works, 1878–1884," by Eliot C. Clarke, M. Am. Soc. C. E.

Respectfully submitted,
G. BOUSCAREN,
ROBERT MOORE,
W. HOWARD WHITE,
Board of Censors to award the Norman Medal.

The Report of the Committee to award the Rowland Prize was read and accepted. It is as follows:

To the American Society of Civil Engineers:

The Committee appointed to award the Rowland Prize for the year terminating on the first day of August, 1885, reports that, in its judgment, the prize should be awarded to Paper No. 295, "Experiments with New Apparatus on Journal Friction at Low Velocities," by A. M. Wellington, M. Am. Soc. C. E.

Respectfully submitted,
MENDES COHEN,
EDWARD P. NORTH,
JOHN BOGART,
Committee.

* Printed separately.

The following summary of replies received in reference to the place for holding the next Convention was presented:

Denver was suggested	by	84
Burlington	"	39
San Francisco	"	4
Saratoga	"	4
New York	"	3
Cincinnati	"	2

The following places were also suggested in the replies received: Newport, Fortress Monroe, White Sulphur Springs, Montreal, Long Branch, Louisville, Washington, Chattanooga, Cleveland, Lake George, Catskill, Albany and Philadelphia.

After discussion, it was resolved to hold the Convention at Denver, or in the neighborhood of that city, and the date, and other details in reference to the Convention, were referred to the Board of Direction, with power.

The replies to the circular in reference to a suggested trip to England during the summer were presented, showing that 78 persons expressed a desire to make such a trip, should it be arranged. A communication was presented from the Director-General of the proposed American Exhibition in London, stating that such exhibition would be postponed until 1887, and extending the invitation to visit England to 1887.

On motion, the subject was laid on the table.

The Committee to confer in reference to a Plan for a Library for Joint Use presented the following report, which was, on motion, accepted, and the Committee continued.

New York, January 19th, 1886.

To the American Society of Civil Engineers:

Gentlemen.—At the last annual meeting you adopted the following: "*Resolved*, That the President be authorized to appoint a committee, consisting of five members, to confer with committees appointed by kindred societies for the purpose of devising and considering a plan for creating a library for the joint use of the organizations represented by the committees in conference; said plan to be reported to the Society for such action as may be desirable."

Your Committee, appointed by the President under that resolution, begs leave to report as follows:

The Committee met twice, and at its second meeting it was joined by Committees from the following societies:

The American Institute of Mining Engineers; The American Society of Mechanical Engineers; The American Institute of Electrical Engineers.

The Committees of the four societies organized on May 13th, 1885, as a Joint Committee, by electing Wm. P. Shinn, of your Committee, as Chairman, and M. N. Forney, of your Committee, as Secretary; the Joint Committee also appointed a Sub-Committee consisting of one Member from each Society, and the Chairman, to procure information.

The Joint Committee has had several meetings.

We find entire unanimity among the members of the Joint Committee, and, so far as their views have been expressed, among the Members of the several societies, as to the desirability of a joint library; and the members of the Joint Committee are practically in accord as to the general plan to be adopted.

Your Committee is encouraged with the prospect of success in securing a plan which will be at once practical and capable of execution, but is not yet prepared to report any details.

With this report of what we believe to be substantial progress, we respectfully request that the Committee be continued.

WM. P. SHINN,
HENRY R. TOWNE,
T. C. CLARKE, } *Committee.*
G. S. MORISON,
M. N. FORNEY,

The Report of the Committee on Uniform Standard Time was presented, and, on motion, accepted, and the Committee continued.

The report is as follows:

ROOMS OF THE SOCIETY, AMERICAN SOCIETY CIVIL ENGINEERS,
NEW YORK, January 20th, 1886.

The Special Committee on Standard Time beg leave respectfully to report.

It may be remembered by Members of the Society, that a few weeks previous to the date of the last annual report, the International Meridian Conference completed its deliberations, and that the President of the United States, in his message at the opening of Congress, drew attention to their proceedings, dwelling upon the unanimity displayed in the votes of the Conference. The delegates composing it, gathered from the entire civilized world, were practically unanimous in the determination of a zero for time and longitude, and with equal unanimity, adopted for all nations a universal day, the hours of which are to be counted from zero to twenty-four.

This authoritative announcement by the President may be accepted as a marked recognition of the admitted importance of a reform in time-reckoning. It is but a few years since any systematic attempts have been made to remodel the old usages, and reach a rational system more in accord with the requirements of the present age, and it is in no small degree due to the persistent efforts which have been made by the American Society of Civil Engineers since the subject was first discussed in 1881, that its present prominence has been obtained; efforts which had only in view the common benefits, in which every locality and every country would equally participate.

The Committee do not now propose to discuss the advantages attainable by the establishment of universal or cosmic time. However much its general application would simplify all problems in which any question of time connected with railway, telegraph and ocean steam service, is

involved, it may be assumed that the busy populations of the world are as yet scarcely prepared to receive it for use in the events of every-day life. A change of this character can be introduced only slowly and gradually. It can only make its way by the force of its necessity and a proper appreciation of the advantages it would confer. There is in the minds of men a strong natural disinclination to depart from old practices, and it is the more remarkable that, notwithstanding this aversion to change, so much progress has been made in time reform within so short a period.

On this continent the standard hour system has been successfully applied. It has been in common use for more than two years, and it has been generally accepted in the United States and Canada as in every respect beneficial and advantageous. If there be localities where this common satisfaction is not experienced, it is at those centers of population which, by their geographical position, come midway between the hour meridians. At such points the notation of time is not confined to one series of numbers. Railway trains arrive and depart by more than one hour standard. There is, under such circumstances, a non-accord of time in the same city, and the old time difficulty, so happily removed from so many other localities on every part of the continent, continues to be experienced.

There is but one remedy for every difficulty of this kind, viz., the adoption of one uniform reckoning in all longitudes, and such would be the effect of universal time alluded to by the President in his annual message. And until we reach the common acceptance of this principle of notation, the inconveniences still remaining in certain centers are obviously unavoidable, and in such localities the evils must continue until cosmic time comes into common use.

We are now but fourteen or fifteen years from the close of the nineteenth century. Scientific men may recollect that the Russian astronomer, Struve, recommended that the change in the Nautical Almanac, by which the ephemerides are to be made to accord with the date-notations, according to universal time, should commence on the change of the century. Possibly that epoch would be equally a suitable occasion to mark the realization of the highest aspirations of the most ardent time-reformers. If so much has been acccomplished since this Society first considered the question, less than five years back, is it too much to expect that in fifteen years all the prejudices which use and habit have engendered, will be conquered, and the public mind prepared for the acceptance in every-day life of a rational scientific time-system, free from all anomalies, and securing complete uniformity in all longitudes on the earth's surface? Possibly, if the circumstances will admit the adoption at that date of cosmic time for all purposes, the change would be considered a fit inauguration of the commencement of the twentieth century.

In science, universal or cosmic time is accepted, but the immediate introduction of it in ordinary life is obviously premature. It will only be step by step that the public will be led to adapt themselves to the change. One step, it is not too soon to consider, that feature in the system alluded to by the President, the numeration of the hours in a single series from midnight to midnight.

This feature has the authority of the International Conference for its introduction. In intelligent circles in Europe, particularly in England and in Russia, also at the antipodes in Australia, the proposal is reported to have been greeted with enthusiasm. The Astronomer-Royal of England, Mr. Christie, has established at Greenwich Observatory a division of the great dial into 24 hours. In London and in other cities, public clocks have been also changed to accustom the English public to this division of the day. Some newspapers in all their announcements adopt the change, and Scientific Societies give notice of their meetings in the same manner as this Society, according to the 24-hour system.

On this Continent there has been no uncertain sound. In the last annual report of the Committee, it was stated that 171 managers of railways in the United States and Canada had declared their readiness to abandon the division of the day into half-days, known as *ante* and *post* meridian, and to accept the numeration of the hours in one series, from midnight to midnight; these managers having under their control some 60,000 miles of railway.

During the past year the seed sown has been fructifying, and many who held back have been won over and have given their adhesion to the movement. Among the many important railways ready to co-operate, some appear to see no necessity for further delay, and desire to secure at once the advantages which will result from the change. At this date it is publicly announced that the Canadian Pacific Railway Company have determined to adopt the 24-hour system, and are actually preparing to make the change at an early day. Such proceedings can be accepted as indicating a proper appreciation of the reform which the American Society of Civil Engineers has advocated, and equally shows the discernment of those who direct the management of the youngest of the transcontinental railways. This practical commencement will, without a doubt, be speedily followed by other railway companies, and before long we may hope to see the 24-hour system coming into general use.

On behalf of the Committee,

SANDFORD FLEMING,
Chairman.

The Committee to present the subject of Time Nomenclature to the General Railway Time Conventions reported progress, and, on motion, the report was accepted and the Committee continued.

The Committee to consider the subject of the Compressive Strength of Cement and the Compression of Mortars and Settlement of Masonry,

reported that the Committee had begun its labors, but had not at present a special report to make. On motion, the report was accepted and the Committee continued.

The Chairman of the Committee to consider changes in the Society's organization, reported that the Committee were unable to agree, and submitted a minority report. After discussion, the subject was referred back to the Committee.

At 13 o'clock recess was taken until 14:30 o'clock.

The session of the Annual Meeting was resumed, President Graff in the Chair. The tellers appointed to canvass the ballot for officers of the Society, reported as follows:

Report of the Tellers appointed to Canvass the Ballot for Officers of the Society for the ensuing year.

ANNUAL MEETING, JANUARY 20TH, 1886.

The Tellers respectfully report as follows:

Total number of ballots received		513
Deduct ballots received from Members not entitled to vote, being in arrears	16	
Deduct duplicate and triplicate ballots and ballots not indorsed	23	
	—	39
Total number found correct and counted		474

For *President:* Henry Flad has received 321 votes; Washington A. Roebling has received 148; William H. Paine has received 1; Fred. Graff has received 1. For *Vice-Presidents:* T. F. Rowland has received 467; T. C. Keefer has received 329; Charles H. Latrobe has received 147; J. B. Eads has received 1; C. Shaler Smith has received 1; C. B. Comstock has received 1; A. M. Wellington has received 1. For *Secretary and Librarian:* John Bogart has received 472; J. J. R. Croes has received 1. For *Treasurer:* J. J. R. Croes has received 472; John Bogart has received 1. For *Directors:* O. W. Barnes has received 144; George S. Greene, Jr., has received 469; William R. Hutton has received 467; W. Howard White has received 328; Wm. G. Hamilton has received 145; O. E. Michaelis has received 142; Henry G. Morris has received 332; Charles L. Strobel has received 324; Geo. S. Morison has received 1; Wm. E. Worthen has received 1: De Volson Wood has received 1; D. J. Whittemore has received 1; A. M. Wellington has received 1; Q. A. Gillmore has received 1; E. P. North has received 1; M. N. Forney has received 1; J. H. Shedd has received 1; A. P. Boller has received 1; Charles Macdonald has received 1; W. S. Rosecrans has received 1; W. Sooy Smith has received 1; Theodore Cooper has received 1.

The following persons have received a majority of votes, there being an excess over 237:

For President: Henry Flad, 321. For Vice-Presidents: Thomas C. Keefer, 329; Thomas F. Rowland, 467. For Secretary and Librarian: John Bogart, 472. For Treasurer: J. James R. Croes, 472. For Directors: Geo. S. Greene, Jr., 469; Wm. R. Hutton, 467; W. Howard White, 328; Henry G. Morris, 332; Chas. L. Strobel, 324.

Respectfully submitted,

Charles H. Swan,
Rob't Cartwright,
J. F. Flagg,
F. C. Prindle.

The following Members were thereupon declared elected Officers of the Society for the ensuing year:

President: Henry Flad.

Vice-Presidents: Thomas C. Keefer, Thomas F. Rowland.

Secretary and Librarian: John Bogart.

Treasurer: J. James R. Croes.

Directors: George S. Greene, Jr., William R. Hutton, W. Howard White, Henry G. Morris, Charles L. Strobel.

Dr. Thomas Egleston, M. Am. Soc. C. E., Member of the Committee on Standard Time, made some remarks upon the general subject of the twenty-four hour system, and upon the adaptation of clocks and watches to that notation.

Captain O. E. Michaelis, M. Am. Soc. C. E., presented a note in reference to the cost of concrete upon a recently executed work.

The President announced the appointment of the following Members upon the Committee to consider the Relation to Each Other of the Sections of Railway Wheels and Rails: Messrs. H. Stanley Goodwin, A. M. Wellington, Geo. S. Morison, Samuel Rea and Thomas Rodd.

On motion it was resolved that the President be authorized to add two names to this Committee at a future time.

Dr. Thomas Egleston, M. Am. Soc. C. E., read a short paper on the Disintegration of the Egyptian Obelisk in the Central Park in New York.

Mr. Richard P. Rothwell, M. Am. Soc. C. E., described a new device for laying submarine tunnels.

Recess was taken until 20 o'clock.

The session of the meeting was resumed at 20 o'clock. Mr. B. S. Church, M. Am. Soc. C. E., Chief Engineer of the Croton Aqueduct Commission, described the works in progress and contemplated, for securing additional water supply for the City of New York.

January 21st, 1886.—An excursion was made over the Hudson River Railroad to the Croton River, the site for the proposed great Dam at Quaker Bridge being first visited. The party then proceeded up the

valley of the Croton to the present Croton Dam. The tunnel for the Aqueduct and the works in progress for the Gate-house at the beginning of the Aqueduct, were examined. By invitation of Mr. Church, lunch was eaten at that point. A special train was then taken on the New York City and Northern Railroad, the route of which is, for a considerable distance, within sight of the line of the Aqueduct, and stops were made at several points. The party descended Shaft No. 17, and saw the progress of work both of the heading in rock tunnel and of the brick conduit in construction and completed. Returning to the city, a trip was made over the Tenth Avenue Cable Road, under the auspices of Colonel Wm. H. Paine, M. Am. Soc. C. E., the Chief Engineer of that road, and the machinery for the propulsion of the cables was examined at the station, One Hundred and Twenty-eighth street and Tenth avenue. The return to the Society House was made over the lines of the Elevated Railroad.

In the evening, a reception, tendered by the Resident Members to the Visiting Members and other guests, was held at the Society House.

The Members of the Society, 147 in number, present at the Annual Meeting, excursions, etc., were: Julius W. Adams, Edward R. Andrews, E. C. Appleton, John W. Bacon, Thomas N. Bailey, A. P. Barnard, O. W. Barnes, L. F. Beckwith, John A. Bensel, Henry A. Bentley, George H. Bishop, H. D. Blunden, John Bogart, Alfred P. Boller, William F. Booth, Robert E. Briggs, Fred. Brooks, Charles O. Brown, Charles B. Brush, Andrew Bryson, L. L. Buck, Frank A. Calkins, Robert Cartwright, S. H. Chittenden, B. S. Church, F. H. Clement, Mendes Cohen, Francis Collingwood, Theodore Cooper, J. James R. Croes, John Y. Culyer, Wendell R. Curtis, Charles G. Darrach, Joseph P. Davis, E. P. Dawley, P. P. Dickinson, Thomas Egleston, Charles E. Emery, S. M. Felton, Jr., John W. Ferguson, C. F. Ferrer, Clark Fisher, J. Foster Flagg, C. E. Fogg, John D. Fouquet, George B. Francis, John R. Freeman, George H. Frost, E. L. B. Gardiner, Henry Goldmark, H. Stanley Goodwin, E. Sherman Gould, Frederic Graff, Samuel M. Gray, George S. Greene, George S. Greene, Jr., Malcolm S. Greenough, Stephen S. Haight, William G. Hamilton, Charles M. Harris, Robert L. Harris, William P. Harris, William J. Haskins, Arthur Haviland, Albert B. Hill, Warren E. Hill, S. Willett Hoag, Jr., Frank W. Hodgdon, Frank H. Howes, Charles W. Hunt, William R. Hutton, George A. Just, Charles Kellogg, Joseph M. Knap, C. H. Latrobe, E. D. Leavitt, Jr., Louis Lesage, G. Leverich, Horace Loomis, Thomas D. Lovett, William W. Maclay, Charles Macdonald, William B. Mackenzie, George B. Mallory, C. C. Martin, C. S. Maurice, Thomas C. McCollom, D. E. McComb, T. H. McKenzie, George W. McNulty, Henry C. Meyer, Thomas C. Meyer, O. E. Michaelis, C. H. Myers, O. F. Nichols, Edward P. North, F. O. Norton, Ellis B. Noyes, F. S. Odell, L. F. Olney, S. B. Opdyke, Joseph O. Osgood, James Owen, A. B. Paine, William H. Paine,

W. Barclay Parsons, Jr., John A. Partridge, H. W. B. Phinney, F. C. Prindle, Chas. Ward Raymond, Samuel Rea, Percival Roberts, Jr., Thomas F. Rowland, G. M. Rusling, J. Gardner Sanderson, D. C. Sanford, C. C. Schneider, William P. Shinn, R. I. Sloan, Maxwell Smith, W. Harrison Smith, Chandler D. Starr, D. McN. Stauffer, Frank S. Stevens, Charles H. Swan, E. Sweet, Henry R. Towne, A. W. Trotter, John G. Van Horne, Edgar B. Van Winkle, Charles D. Ward, Lebbeus B. Ward, F. W. Watkins, William Watson, Albert L. Webster, A. M. Wellington, Nelson J. Welton, E. B. Weston, W. Howard White, Frank O. Whitney, William H. Wiley, F. N. Willson, Sebastian Wimmer, C. J. H. Woodbury, William E. Worthen, Preston K. Yates and A. J. Zabriskie.

REPORT OF THE BOARD OF DIRECTION FOR THE YEAR ENDING DECEMBER 31ST, 1885.

PRESENTED AND ACCEPTED AT THE ANNUAL MEETING, JANUARY 20TH, 1886.

The Board of Direction, in compliance with the provisions of the Society law, presents its report for the year ending December 31st, 1885.

MEMBERSHIP.

As shown by the tabular statement hereinafter given, there has been, during the year, an addition of 74 to the various grades of Society membership. In this nominal addition of 74 there are 3 former Juniors transferred to Members, therefore the actual new additions to the Society membership during the year number 71.

The losses from the Society membership have been 21, being 12 by death, 5 by resignation and 4 dropped. The number of persons now connected with the Society is 928, being greater by 50 than at the end of the previous year.

The actual net increase during the year, and present total in each class of membership, are:

Honorary Members,	decrease during year	2	Total.....	8
Corresponding Members,		..	"	3
Members,	increase "	44	"	701
Associates,	decrease "	1	"	33
Juniors,	increase "	12	"	89
				834
Fellows not included above,	decrease "	3	"	54
Subscribers to Building Fund, not included above.....				40
	Increase during year.....	50	Total.....	928

Tables showing the classification of membership at the beginning of the year, and the changes during the year, are given at a subsequent part of this report.

THE ANNUAL CONVENTION.

The Annual Convention was held at Deer Park, Md., on the line of the Baltimore and Ohio Railroad, on June 24th, 25th and 26th of the past year. A detailed report of the Convention has been published in the Proceedings for June last. Previous to the Convention a large number

of Members of the Society met in Baltimore, and, under the escort of Members resident in that city, and of officers of the Baltimore and Ohio Railroad, visited the freight and marine terminals, the elevators and docks of that railroad, and also enjoyed an excursion upon the harbor of Baltimore and to the United States forts in the vicinity. A visit was also made, under the escort of the Chief Engineer of the Baltimore Water Department, to the water-works and the source of water supply of that city. A special train conveyed the party from Baltimore to Deer Park, stops being made to inspect the Mt. Clare shops of the road, and also at a number of points of interest on the line. On one of the days of the Convention, a part of the day was spent in a trip over the Mountain Division of the railroad.

In the last Annual Report of the Board, particular attention was called to the subject of the methods for holding future Conventions. It was suggested that some, if not all, of our Conventions should be held at such places and in such a manner as to secure the results outlined in that report, which are:

(*a.*) The presentation, consideration and undisturbed discussion of professional subjects.

(*b.*) The opportunity for free intercourse between Members of the Society gathering at our Conventions from all parts of the United States, and in fact of the world.

(*c.*) Such opportunities for social recreation as may not interfere with, but rather aid in, the other two objects mentioned above.

Of course, visits to points of engineering interest should not be neglected.

The Convention at Deer Park was very successful, giving an opportunity for carrying out the suggestions referred to, and in many respects it was particularly satisfactory, more especially in the remarkable value of the discussions, and the importance of the papers and subjects presented during its meetings.

Invitations have been presented to the Society from the citizens of Denver, Colorado, and of Burlington, Vermont, to hold the next Annual Convention at each of these places. These invitations have been announced in a general circular, the reply to which, with the suggestions of the various Members of the Society, will be presented for your consideration at this meeting.

Meetings of the Society.

The regular meetings have been well attended, the attendance having been twenty per cent. greater than during any previous year, and, as in past years, the number of Members not resident in New York who have taken part in these meetings has been large, and the number of contributions of discussions from Non-Resident Members has been very gratifying.

The collations following the meetings on the first of the month have been continued through the subscriptions of Resident Members, and have offered opportunities for conversation which probably would not otherwise have been secured. As stated in a former report of the Board, no funds of the Society are used for these collations.

Transactions.

The Transactions have been issued during the year with regularity, and the very valuable contributions by our Members and by other engineers to the Transactions are particularly acknowledged by the Board. The number of pages printed yearly is increased as rapidly as the income of the Society will warrant. During the past year 162 pages of the Transactions and Proceedings have been issued beyond the highest number ever printed in any previous year. The Board has adopted the course of devoting by far the larger part of the income of the Society to the publication of its Transactions, as will be seen by the Report of the Treasurer, in which it may also be noted that the amounts charged to postage, to salaries, and to the work of committees, are largely expended in the preparation and issue of the Transactions. The Board believes that it is proper so to devote as much as possible of our income to the publications of the Society.

The Society House and the Building Fund.

There have been but two contributions to the Building Fund during the year. Every contribution to this fund reduces materially the rental paid by the Society for its house, which rental is now paid in the form of interest upon the mortgage and of the taxes upon the property. The house itself is an excellent investment, gradually increasing in value each year, and the Board again desires to call attention to the great desirability of reducing the mortgage upon the property by contributions to the Building Fund of the Society, from persons interested in its welfare.

Fellowship Fund.

During the past year but one Fellow of the Society has been elected, and the Fellowship Fund has therefore been increased by only one subscription.

The Board desires to impress upon the Members of the Society that it is probable that the presentation of the subject of association with the Society as a Fellow, to many gentlemen not otherwise connected with it, would result in a large increase of this important Fund, the income from which is devoted to our publications. Connection with the Society as a Fellow secures all the publications of the Society and a participation in all the privileges, except the right to vote.

Advance Notices of Candidates for Membership.

The issue of notices to all Members of the Society, giving the names and addresses of Candidates for Membership thirty days previous to the consideration by the Board of Direction of the applications, has proved of great value in securing desirable information as to those desiring to join the Society.

The Committee on Uniform Standard Time.

This Committee will present a report of progress at this meeting.

The Committee on Preservation of Timber.

This Committee presented at the Convention in June of the past year, a valuable report, which was published in full in the Transactions of the Society for July, and the appendices to which, written by a number of Members of the Society, and by others, were printed in the Transactions for August.

The Committee having completed its labors in the presentation of this report, was discharged from further duty by the Convention, with the thanks of the Society.

The Committee on a Uniform System for Tests of Cement.

The Committee on a Uniform System for Tests of Cement presented a report at the Annual Meeting of the past year, and also at the Convention in June last, and the Committee was then discharged, with the thanks of the Society.

The report was printed in the Transactions of the Society for November of the past year.

The Committee on the Compressive Strength of Cements and the Compression of Cements and Settlement of Masonry.

This Committee, appointed under the action of the Society at the last Convention, has inaugurated its labors by the issue of a circular of information.

It will make a report of progress at this meeting.

The Committee to Consider Changes in Organization.

This Committee was appointed under a resolution adopted at the business meeting of the Society during the last Annual Convention.

It is understood that a report will be presented at the present Annual Meeting.

The Committee to Confer with Kindred Societies for the Consideration of a Plan for Creating a Library for Joint Use.

This Committee was appointed under a resolution adopted at the last Annual Meeting of the Society, and has the subject entrusted to it still under consideration and progress.

Amendments to the Constitution.

At the last Annual Meeting, an amendment to the Constitution, providing for the compounding of annual dues by single payments, was discussed, amended and recommended to the Society for adoption. The vote on the amendment was canvassed at the meeting of the Society of March 4th, 1885, and was adopted by a large majority of the votes cast.

This amendment provides for the compounding for future annual dues by the payment of $250, with the provision that Members who, at any time, become resident, shall be, during such residence, liable to the payment of the difference between the annual dues of Resident and Non-Resident Members. All dues of every nature and kind may be compounded for by a total payment of $325.

The Norman Medal.

The Norman Medal for the year 1884 was awarded to paper No. 279, entitled Experiments on the Strength of Wrought-Iron Struts, the author being James Christie, M. Am. Soc. C. E.

The Board of Censors to award this medal for the past year will present its report at this meeting.

The Rowland Prize.

The Rowland Prize for 1884 was awarded to paper No. 274, entitled Water Power with High-Pressures and Wrought-Iron Water-Pipe, the author being Hamilton Smith, Jr., M. Am. Soc. C. E.

The Committee to award this prize for the past year will present its report at this meeting.

The Committee on the Proper Relation to Each Other of the Sections of Railway Wheels and Rails.

At the last Convention a resolution was presented authorizing the appointment of a Committee on this subject. This resolution was submitted to a vote by letter ballot, the vote being canvassed on October 7th, 1885, and the resolution was carried.

The organization of this Committee has not yet been perfected.

Junior Membership.

At the meeting of the Society of November 4th, 1885, a resolution was adopted requesting the Board of Direction to issue a circular calling the attention of the Members to the desirability of adding to the Junior membership, and of using their personal influence with young men towards inducing them to make application in the usual way for Junior membership.

This circular has been issued and sent to all the Members of the Society.

Membership Tables.

The following tables show the changes and additions during the year in the various classes of membership:

On January 1st, 1885, the date of the last report, the membership in the Society was:

Honorary Members, resident...	2	Non-resident....	8	Total...	10
Corresponding Members.....		"	3	" ..	3
Members, resident.....	130	"	527	"	657
Associates "	12	"	22	"	34
Juniors, "	16	"	61	"	77
					—768
Making resident.....	160	Non-resident....	621		
Total.....					781

Fellows, 66, of whom 8 Members and 1 Honorary Member are included above, leaving..... 57

Subscribers to the Building Fund, 137, of whom 93 are entered in one or other of the above classifications, and 4 deceased, leaving 40

Total connected with the Society, January 1st, 1885.....878

At the present date, January 1st, 1886, the membership is:

Honorary Members, resident...	2	Non-resident....	6	Total...	8
Corresponding Members.....		"	3	" ...	3
Members, resident.....	131	"	570	"	701
Associates, "	10	"	23	"	33
Juniors, "	23	"	66	"	89
					—823
Making resident.....	166	Non-resident....	668		
Total.....					834

Fellows, 62, of whom 8 Members are included above, leaving..... 54

Subscribers to the Building Fund, 139, of whom 92 are entered in one or other of the above classes, and 7 deceased, leaving 40

Total connected with the Society, January 1st, 1886.....928

The additions during the past year to the several classes of Society membership have been:

Members qualified	56
Associates qualified	2
Juniors qualified	15
Fellow qualified	1
Total additions to the several classes of membership	74
Subscribers to the Building Fund, 2, who are otherwise connected with the Society	00
Total additions	74

The decrease during the year in the several classes of membership has been:

Honorary Members	Died 2	2
Members	" 4 Resigned 4 Dropped 4	12
Associates	" 2 " 1	3
Juniors	Transferred to Members 3	3
Fellows	Died 4	4
Totals: Deaths 12, Resignations 5, Dropped 4, Transferred, 3		24

There has thus been an addition of 74 to the various classes of membership, and a decrease of 24, making the actual net additions during the year 50 in number.

On January 1st, 1885, there were, as stated in the last Annual Report, 18 proposals pending. Ninety-eight proposals have been received during the year; 51 candidates have been elected Members, of whom 3 were transferred from Juniors; 2 candidates have been elected Associates; 15 candidates have been elected Juniors.

Fifty-six persons have during the year qualified as Members; 2 have qualified as Associates; 15 have qualified as Juniors; 1 has qualified as Fellow; 4 candidates elected during the year as Members have not yet qualified. There are 21 proposals now pending.

Twenty-two meetings of the Society were held during the year, one of which was the Annual Meeting, held in New York, January 21st and 22d, and another the Annual Convention, held at Deer Park, Maryland, June 24th, 25th and 26th; all the sessions of the Convention, including the business meeting, being counted as one meeting of the Society. Meetings have been held on the first and third Wednesday of each month, except July and August.

Twenty-three meetings of the Board of Direction have been held during the year.

The Library has been increased during the year by the following additions:

Books and Pamphlets	709
Maps, Plans, Drawings, Charts, Photographs and Engravings	531

Reports made during the year have been as follows:

By the Board of Direction: The Annual Report.

By the Finance Committee: Annual Report on the Finances of the Society; Quarterly Reports to the Board of Direction.

By the Library Committee: Regular Monthly Reports on the Library and on Publications.

By the Secretary: Monthly Reports to the Board of Direction; Occasional Reports on Current Business.

By the Treasurer: The Annual Report of the Treasurer: Monthly Reports to the Board of Direction.

By the Committee on Uniform System for Tests of Cement: Final Report and the Committee discharged.

By the Committee on Preservation of Timber: Final Report and the Committee discharged.

By the Committee on Uniform System for Standard Time: One Report.

By the Nominating Committee: Two Reports.

The Society has lost by death during the term covered by this report two Honorary Members, Messrs. John B. Jervis and Emile Malézieux; four Members, Messrs. Theophilus E. Sickels, Henry M. Wightman. Wilmon W. C. Sites and Louis R. Walton; two Associates, Messrs. Henry H. Gorringe and Arba R. Haddock; and four Fellows, Messrs. William C. Kingsley, M. T. Seymour, Thomas C. Durant and Frederick W. Merz.

Respectfully submitted,

JOHN BOGART,

Secretary.

REPORT OF THE TREASURER FOR THE YEAR ENDING DECEMBER 31st, 1885.

RECEIPTS.

Balance on hand December 31st, 1884 :				
Building Fund		$426.03		
General Fund		4 550.87		
				$4 976.90
Receipts during year :				
Entrance Fees			$1 920.00	
Current Dues :				
From 93 Resident Members	$2 272.50			
" 384 Non-resident Members	5 605.87			
" 9 Resident Associates	135.00			
" 10 Non-resident Associates	100.00			
" 18 Resident Juniors	215.00			
" 56 Non-resident Juniors	535.00			
		$8 863.37		
Past Dues :				
From 12 Resident Members	$385.00			
" 40 Non-resident Members	569.50			
" 4 Resident Associates	75.00			
" 3 Resident Juniors	25.00			
" 1 Non-resident Junior	10.00			
		1 064.50		
Dues for year beginning January 1st, 1886 :				
From 21 Resident Members	$512.50			
" 27 Non-resident Members	420.00			
" 2 Non-resident Associates	20.00			
" 1 Resident Junior	15.00			
" 4 Non-resident Juniors	40.00			
		1 007.50		
			10 935.37	
Sales of Publications			1 023.66	
Certificates of Membership			96.75	
Advertisements			178.00	
Interest on Fellowship Fund Bonds		$480.00		
" Savings Bank Deposit		32.96		
" Norman Medal Fund Bond		70.00		
" Railroad Stock		36.23		
" Rowland Prize Fund Bond		60.00		
" General Society Fund Bonds		120.00		
			799.19	
Subscriptions to Building Fund			225.00	
Fellowship Fees			150.00	
Other sources			6.15	
				15 334.12
				$20 311.02

DISBURSEMENTS.

Interest on Mortgage	$800.00	
Taxes	523.06	
Publications	5 627.86	
Stationery and Printing	822.96	
Postage	1 090.01	
Library	1 316.77	
Salaries	3 000.00	
Convention and Annual Meeting	1 066.74	
Janitor, House Supplies, Fuel, Water and Gas	1 616.91	
Certificates of Membership	106.40	
Insurance	200.83	
Norman Medal and Rowland Prize	133.60	
Other expenditures	336.79	
Finance—Treasurer's Books	525.00	
Work of Committees	514.35	
		$17 681.28
Payments from Building Fund	.....	651.03
Transferred to Savings Bank	.....	32.96
		$18 365.27
Balance on hand	.....	1 945.75
		$20 311.02

The funds of the Society are as follows:

Fellowship Fund:

Eighty-seven subscriptions to December 31, 1884.....	$9 200.00
Premium and accumulated interest December 31, 1884.	1 903.69
Fund on hand December 31, 1884.....	$11 103.69
One subscription during 1885.....	150.00
Interest received during 1885.....	482.96
	$11 736.65
Expended for publications during 1885.....	998.37
	$10 738.28

The present investment of the Fund is:

Eight Pennsylvania Railroad Six per cent. Bonds, cost	9 889.32
Deposit in Seamen's Bank for Savings.....	848.96
	$10 738.28

Norman Medal Fund:

One Certificate Croton Aqueduct Stock, New York City.....	1 000.00

Building Fund:

Receipts previous to January 1, 1885.....	$17 517.00
" during 1885.....	225.00
	$17 742.00

Expended:

For Legal Services, Circulars, etc.....	$355.03
For Improvements on Property.....	3 386.97
Payments on Purchase.....	14 000 00
	$17 742.00

Rowland Prize Fund:

One Pennsylvania Railroad General Mortgage Six per cent. Bond, cost.....	$1 222.50

General Investment :

10 Shares New York Central and Hudson River Railroad Stock	$1 000.00
1 Consolidated Certificate New York Central and Hudson River Railroad Stock	35.00
2 Pennsylvania Railroad General Mortgage Six per cent. Bonds, cost	2 445.00
	$3 480.00

Respectfully submitted,

J. James R. Croes,

Treasurer.

REPORT OF THE COMMITTEE ON FINANCE.

Presented and Accepted at the Annual Meeting, January 20th, 1886.

The Finance Committee has the honor to report that they have performed the usual duty of auditing all the bills that have been paid by the Treasurer during the past year, and have found that each bill has been charged to its proper fund, and that the several sums have not exceeded the amounts appropriated by the Board of Direction for the purposes specifically mentioned. Also that the Committee has, at the end of the year, carefully examined all the assets of the Society, and has found that the reports of the Secretary and Treasurer give a correct account of the same.

A change has been made in the investment of the Society by selling $10\frac{35}{100}$ shares of the New York Central and Hudson River Railroad Stock, and buying 10 shares Consolidated Gas Company of New York City, and a balance of $62.50, which remained from proceeds of sale of the New York Central after purchasing the Gas Stock, has been deposited in the Seamen's Bank for Savings. This change of investment was not completed in time to appear on the Treasurer's books when written up to December 31st, 1885.

Respectfully submitted,

G. S. Greene, Jr.,

Wm. R. Hutton,

Finance Committee.

LIST OF PUBLICATIONS AND PAPERS RECEIVED FOR LIBRARY.

Appendix to Annual Report of the Board of Direction, January 20th, 1886.

The following papers are contributed to the Society, or are received in exchange for Transactions :

American Architect and Building News	Weekly	Boston.
American Engineer	"	Chicago.
American Gas Light Journal	Semi-Monthly	New York.
Annales des Travaux Publics	Monthly	Paris.
Army and Navy Journal	Weekly	New York.
Builder	"	London.
Building and Engineering News	"	"
Bulletin American Iron and Steel Association	Semi-Monthly	Philadelphia.
Bulletin du Canal Interocéanique	"	" Paris.
Commissioner of Patents' Journal	Semi-Weekly	London.
Der Civilingenieur	Monthly	Leipsig.
Deutsche Bauzeitung	Weekly	Berlin.
Eizen Zeitung	"	Vienna.
Electrical Review	"	New York
Engineer	"	London.
Engineering	"	"
Engineering Era	Semi-Monthly	Cleveland.
Engineering and Mining Journal	Weekly	New York.
Engineering News and American Contract Journal	Semi-Monthly	"
Genie Civil	"	" Paris.
International Standard	Quarterly	Cleveland.
Iron	Weekly	London.
Iron Age	"	New York.
Journal of the Association of Engineering Societies	Monthly	"
Journal of Society of Arts	Weekly	London.
Journal of Gas Lighting	"	"
Locomotive	Monthly	Hartford.
Manufacturer and Builder	"	New York.
Manufacturer and Iron World	Weekly	Pittsburgh.
Magazine of American History	Monthly	New York.
Mechanical News	Semi-Monthly	"
Norsk Teknisk Tidsskrift	Monthly	Christiania.
Nouvelles Annales de la Construction	"	Paris.
Portefeuille Economique des Machines	"	"
Record of Scientific Literature	"	New York.
Railroad Gazette	Weekly	"
Railway Age	"	Chicago.
Railway Herald	Monthly	Buffalo.
Railway Review	Weekly	Chicago.
Railway World	"	Philadelphia.
Reportorium der Technischen Literatur		Leipsig.
Revue Générale des Chemins de fer	Monthly	Paris.
Sanitary Engineer	Weekly	New York.
Scientific American	"	"
Scientific American Supplement	"	"

Teknisk Tidsskrift	Monthly	Stockholm.
Techniker	Semi-Monthly	New York.
Telegraph Journal and Electric Review	" "	London.
Van Nostrand's Magazine	Monthly	New York.
Zeitschrift fur Bauwesens	Quarterly	Berlin.

The following are subscribed for :

American Bookseller	Semi-Monthly	New York.
American Library Journal	Monthly	"
Publishers' Weekly	Weekly	"
Science	"	Cambridge.
U. S. Official Postal Guide	Monthly	Boston.

The Society has received during the year, in exchange for the Transactions, official publications of the following associations. in many instances for preceding years :

Aeronautical Society of Great Britain	London.
Academy of Sciences	Washington.
Akademie des Bauwesens	Berlin.
American Institute of Architects	New York.
American Institute of Electrical Engineers	"
American Institute of Mining Engineers	"
American Iron and Steel Association	Philadelphia.
American Society of Mechanical Engineers	New York.
Annales de Construcciones Civiles y de Minas	Lima.
Annales des Ponts et Chausées	Paris.
Argentine Scientific Society	Buenos Ayres.
Association of Civil Engineers	Lisbon.
Astor Library	New York.
Austrian Society of Engineers and Architects (Two Publications)	Vienna.
Boston Public Library	Boston.
Boston Society of Civil Engineers	"
Canadian Institute	Toronto.
Civil Engineers' Society of St. Paul	St. Paul.
Civil Engineers' Club of Cleveland	Cleveland.
Colegio N. Rosales	Culiacan, Mexico.
Die Administration der "Mittheilungen"	Vienna.
Engineer Department, U. S. A	Washington.
Engineers' Club of Philadelphia	Philadelphia.
Engineers' Club of St. Louis	St. Louis.
Engineers' Society, Western Pennsylvania	Pittsburgh.
Franklin Institute Journal	Philadelphia.
Imperial Hochschule	Berlin.
Imperial School	Moscow.
Imperial Technic Society of Russia	St. Petersburg.
Imperial University	Tokio.
Institution of Civil Engineers	London.
Institution of Civil Engineers of Ireland	Dublin.
Institution of Engineers and Shipbuilders of Scotland	Glasgow.
Institution of Mechanical Engineers	London.
Iron and Steel Institute	"
Liverpool Engineering Society	Liverpool.
Massachusetts Institute of Technology	Boston.
McGill University, Department of Science	Montreal.
Mechanics' Institute	San Francisco.
Midland Institute Mining, Civil and Mechanical Engineers	Barnsley, Eng.

Military Service Institution of the United States.....Governor's Isld., N.Y.
Mining Institute of Scotland.....Hamilton.
New York Meteorological Observatory.....New York.
North of England Institute of Mining and Mechanical Engineers.....Newcastle-on-Tyne.
Rensselaer Society of Engineers.....Troy.
Riga Technical Society.....Riga.
Royal United Service Institution.....London.
School of Mines, Columbia College.....New York.
Seismological Society of Japan.....Tokio.
Smithsonian Institution.....Washington.
Society of Arts.....London.
Society of Civil Engineers.....Paris.
Society of Engineers.....London.
Society of Engineers and Architects.....Cologne.
Society of Engineers and Architecs.....Hannover.
Society of Engineers and Architects of Hungary.....Budapest.
Society of Engineers and Architects of Saxony.....Dresden.
Stevens Institute of Technology.....Hoboken.
Swedish Society of Engineers.....Stockholm.
Technical Society of the Pacific Coast.....San Francisco.
Technischen Hochschule.....Aachen.
Technischen Hochschule.....Hannover.
Thayer Scientific School, Dartmouth College.....Hanover.
United States Agricultural Department (Division of Forestry).....Washington.
United States Coast and Geodetic Survey..... "
United States Geological Survey..... "
United States Light-house Board..... "
United States Naval Institute.....Annapolis.
United States Naval Observatory.....Washington.
United States Ordnance Department..... "
United States Patent Office..... "
University of Michigan.....Ann Arbor.
Verein Deutscher Ingenieure.....Berlin.
Western Society of Engineers.....Chicago.

LIST OF MEMBERS.

ADDITIONS.

MEMBERS.		Date of Election.
APPLETON, ELLERY CUSHING.....	Canajoharie, N. Y.....	June 3, 1885.
BONZANO, MAXIMILIAN FERDINAND,	Division Engineer Philadelphia and Reading R. R., Philadelphia, Pa.....	Jan. 6, 1886.
FULLER, FRANKLIN IDE.....	8 Stark st., Portland, Oregon,	" " "
KITTREDGE, GEORGE WATSON.....	Engineer Maintenance of Way, Muskingum Valley Division, Pittsburgh, Cincinnati and St. Louis Ry., Zanesville, Ohio.....	" " "

		Date of Election.
Reed, Henry Wadsworth	Master of Roadway, Savannah, Florida and Western Ry., Waycross, Ga	Jan. 6, 1886.
Rudloff, Henry Frederic	Chief Engineer Caracas and Antimano Ry., Caracas, Venezuela	" " "

CHANGES AND CORRECTIONS.

MEMBERS.

Atwood, William H.....Tampa, Florida.
Blackwell, Charles.....Union Pacific Ry., Omaha, Nebraska.
Childs, James E.....General Manager New York, Ontario and Western Ry., 15 Broad st., New York City.
Cunningham, David W.....45 South Ninth st., Minneapolis, Minn.
Davis, Joseph P.....1 East Ninth st., New York City.
Doran, Frank C.....P. O. Box 179, Los Angeles, Cal.
Frith, Arthur J.....(Care Western Steel Co.), St. Louis, Mo.
Goad, Charles E.....4 Finsbury Circus, London, E. C., England.
Greene, Francis V.....280 Broadway, New York City.
Holman, M. L.....77 East May st., St. Louis, Mo.
Jennings, William T.....38 Stanley Crescent, Toronto, Canada.
Latham, H. H.....180 and 182 Monroe st., Chicago, Ill.
Mansfield, M. W.....Superintendent Indianapolis and Vincennes R. R., Indianapolis, Ind.
Marsland, Edward.....Room 156, Post Office Building, New York City.
Mitchell, Henry.....U. S. Coast and Geodetic Survey, Washington, D. C.
Odell, Frederick S.....45 West One Hundred and Twenty-sixth st., New York City.
Paine, Charles.....128 West Fifty-ninth st., New York City.
Van Sant, R. L.....(Care Superintendent Maintenance of Way Texas and St. Louis Ry.), Texarkana, Texas.
Vaughan, F. W.....De Funiak Springs, Florida.

JUNIORS.

Breithaupt, W. H.....Berlin, Ontario, Canada.
Marvin, Charles E.....Road Department Louisville and Nashville R. R., Earlington, Ky.

DEATH.

Flint, Edward A.....Elected Member May 18, 1870; died January 23, 1886.

American Society of Civil Engineers.

PROCEEDINGS.

Vol. XII.—February, 1886.

MINUTES OF MEETINGS.

(Abstract of such as may be of general interest to members.)

OF THE SOCIETY.

February 3d, 1886.—The Society met at 20 o'clock, Vice-President Thomas F. Rowland in the Chair.

The following candidates were elected as Members: Edward William Eckert, Massillon, Ohio; James Ellison Mills, Quincy, Cal.; Edward Thomas Wright, Los Angeles, Cal. As Associates: George Lord Burrows, Saginaw, Mich.; Palmer Chamberlaine Ricketts, Troy, N. Y.

A paper by T. H. McKenzie, M. Am. Soc. C. E., on the Waterworks of Southington, Connecticut, was read and discussed.

February 17th, 1886.—The Society met at 20 o'clock, J. James R. Croes, Treasurer Am. Soc. C. E., in the Chair.

The deaths of Mr. Edward A. Flint, M. Am. Soc. C. E., of Brookline, Mass., on January 23d, 1886, and of Mr. Louis R. Walton, M. Am. Soc. C. E., of Earlington, Ky., on November 9th, 1885, were announced.

A paper by Clemens Herschel, M. Am. Soc. C. E., On the Work Done for the Preservation of the Dam at Holyoke, Mass., in 1885, and on

some studies for a new stone dam for the same place was read by the author and discussed.

OF THE BOARD OF DIRECTION.

JANUARY 13TH, 1886.—Financial business was transacted. The draft of the Annual Report prepared by the Secretary was considered, and the Report adopted.

JANUARY 27TH, 1886.—In accordance with the provisions of the Constitution, the following Standing Committees were appointed:

On Finance.—Messrs. George S. Greene, Jr., W. Howard White, Henry G. Morris.

On Library.—J. James R. Croes, Thomas C. Keefer, William R. Hutton.

Applications were considered. Appropriations were made.

FEBRUARY 3D, 1886.—General business was transacted. It was ordered that the card calendar to be issued for the current year should have all time announcements on the 24-o'clock system.

ADDITIONS TO

LIBRARY AND MUSEUM.

From American Institute of Mining Engineers, Dr. R. W. Raymond, Secretary, New York City:

The Flow of Air and other Gases. Fred. W. Gordon.

The Product and Exhaustion of the Oil Regions of Pennsylvania and New York. Charles A. Ashburner.

The Engineer and the Wage-Earner. J. C. Baylis.

Note on the Contraction of Iron on Sudden Cooling. Henry M. Howe.

Note on an Exhibition of Banded Structure in a Gold Vein. Charles M. Rolher.

The Amalgamation of Gold Ores, and the Loss of Gold and Silver in Chloridizing-Roasting in the Stetefeldt Furnace. C. A. Stetefeldt.

Biographical Notice of Charles O. Thompson. Philip M. Moew.

The Picton Coal Field. Henry S Poole.

The Present Value of Steel Castings. Arthur V. Abbott.

The Distribution and Proportions of American Blast Furnaces. John Birkinbine.

The Works of the Blast Furnaces of the North Chicago Rolling Mill Co. Fred. W. Gordon.

A New Method for the Determination of Phosphorus in Iron and Steel. J. B. Mackintosh.

The Geology of Natural Gas. Charles A. Ashburner.

Gordon's Improved Whitwell-Coper Fire-brick Hot-Blast Stove. Victor O. Strobel.

Basic Refractory Materials. T. Egleston.

Proceedings of the Forty-third Meeting, Halifax, Nova Scotia, September, 1885.

List of Officers, Members, Rules, etc., November, 1885.

The Improved Brücker Cylinders. R. W. Raymond.

Quicksilver Condensation at New Almaden. Samuel B. Christie.

An Electrical Furnace for Reducing Refractory Ores. Dr. T. Sterry Hunt.

Discussion of Professor Byron W. Cheever's Paper upon the Estimation of Manganese, Carbon and Phosphorus in Iron and Steel. A. E. Hunt and George H. Clapp.

Notes on Certain Iron Ore Deposits in Colorado. Charles M. Rolker.

The Wolf Benzine-Burning Safety Lamp. E. J. Schnitz.

Notes on the Leadville Ore Deposits. Charles M. Rolker.

Topographical Models: their Construction and Uses. A. E. Lehman.

The Sydney Coal Field, Cape Breton, N. S. W. Roulledge.

The Upper Measure Coal Field of Tennessee. Henry E. Colton.

From American Iron and Steel Association, Philadelphia:

A Letter to the Secretary of the Treasury on the Question of Tariff Revision, with an Appendix.

From American Society of Mechanical Engineers. Prof. F. R. Hutton, Secretary, New York City:

Transactions. Vol. VI. 1885.

From T. Appleton, East Saginaw, Mich.:

First Annual Report of the Board of Public Works of the City of East Saginaw, Mich., for the fiscal year ending January 5th, 1886.

From John W. Bacon, Danbury, Conn.:

Thirty-third Annual Report of the Railroad Commissioners of the State of Connecticut for 1885.

From Edward A. Barber, Philadelphia:

The *American Antiquarian* for October, 1883; January-July, 1884; May-September, 1885.

From H. A. Bentley, Newport, R. I.:

Report of the Consulting Engineers on Examination of the Sewerage System of the City of Newport, R. I., under the direction of the City Council, November 27th, 1885.

From William Bliss, President Boston and Albany Railroad, Boston:

Annual Reports of the Boston and Albany Railroad Company—1st to 4th, 1868 to 1871; 6th to 12th, 1873 to 1879; 14th to 18th, 1881 to 1885.

From James P. Bogart, New Haven, Conn.:

Fifth Report of the Shell-Fish Commissioners to the State of Connecticut to the General Assembly, January Session, 1880.

From Boston Public Library, Boston:

Thirty-third Annual Report of the Trustees of the Public Library. 1885.

From Bureau of Education, Washington, D. C.:

Historical Sketches of the Universities and Colleges of the United States.

Circulars of Information of the Bureau of Education, Nos. 2 and 4. 1885.

From Bureau of Navigation, Navy Department, Washington, D. C.:

Naval Professional Papers, as follows:

No. 13—Magnetism: its Principles and Application to Ships and Compasses.

No. 14—Experiments with Steel.

No. 15—Ships, Guns and Armor.

No. 16—Engines, Boilers and Torpedo Boats.

No. 17—Magnetism of Iron and Steel Ships.

No. 18—Training of Enlisted Men.

Report of the Gun-Foundry Board, with Supplement. 1884.

Report of the British Naval and Military Operations in Egypt. 1882. Part 1, Text; Part 2, Plates.

Examples, Conclusions, and Maxims of Modern Naval Tactics. 1884. Text and Plates.

Papers on Naval Operations during the year ending July, 1885.

Report on the Exhibits at the Crystal Palace Electrical Exhibition, 1882.

Report upon the Comparative Merits of Anthracite and Bituminous Coal for Naval use.

Report of Lieutenant Giles B. Harber, U. S. N, of his Search for the Missing People of the Jeannette Expedition, etc.

Annual Report of the Secretary of the Navy for the year 1885.

Ships of War. Francis T. Bowles.

Report of the Surgeon-General of the Navy for the year 1884.

Register of the Commissioned and Warrant Officers of the Navy of the United States, including Officers of the Marine Corps. January 1, 1886.

From F. W. Bussing, Editor of the *Deutsche Bauzeitung*, Berlin, Prussia:

Hülfswissenschaften zur Baukunde. Part 1.

From Eliot C. Clarke, Boston:

Report of a Commission to Consider a General System of Drainage for the Valleys of the Mystic, Blackstone and Charles Rivers, Mass., 1886.

From L. E. Cooley, Evanston, Ill.:

A Rational Policy of Public Works. L. E. Cooley.

From Elmer L. Corthell, New York City:

The Atlantic and Pacific Ship Railway across the Isthmus of Tehuantepec, in Mexico, considered Commercially, Politically and Constructively. Elmer L. Corthell, Chief Engineer.

Discusion del Opusculo de E. Sweet. La Ampliacion Radical del Canal Erie. E. L. Corthell.

From William A. Crafts, Clerk Board of Railroad Commissioners, Boston:

Sixth Annual Report of the Board of Railroad Commissioners for 1874.

Returns of the Railroad and Street Railway Corporations as reported to the Board of Railroad Commissioners for the year ending September 30, 1877.

Thirteenth Annual Report of the Board of Railroad Commissioners for the year 1881.

From Lieut-Col Wm. P. Craighil, Baltimore:

Strategy and Tactics. Gen. G. H. Dufour.

From Joseph P. Davis, New York City:

Argument of Mr. James J. Storrow and Mr. Edward N. Dickerson for Mr. Bell and the Bell Company. In the Matter of Applications for Leave to Bring Suits in the Name of the United States to Cancel the Bell Patent, 174,405, of March 7, 1876.

Manufacturer and Builder. Vols. I to VII, 1869 to 1875, inclusive.

Trial of Lynn, Mass., Pumping Engine, 1873.

Specifications for Paving to be Executed for the Health Committee of the Borough of Liverpool.

Of Sewerage Work to be Executed for the Health Committee of the Borough of Liverpool.

Sheets of Apportionment of Cost of Paving, Channeling, Curbing and Flagging.

Boston, Mass., Municipal Register for the years 1873-74-75-77-79.

Auditor's Report of the City of Boston for the years 1872 to 1878, inclusive.

Thirty-third, Thirty-fourth and Thirty-fifth Annual Reports of the Board of Education of Boston, Mass., 1869 to 1871, inclusive.

The Census of Massachusetts for the year 1875. Vols. I, II and III.

Report of the School Committee of Boston, Mass., 1871-72-73-75.

Manuscript Record of Tests of Turbines.

Report of Boston Water Board on supply of Cochituate Water for East Boston, Mass., 1879.

First Annual Report of the Boston Water Board for the year ending April 30, 1877
Thirty-fourth and Thirty-fifth Annual Reports of the Boston Fire Department, 1871–72.
Report of the Commissioners appointed to Investigate the Cause and Management of the Great Fire in Boston.
Report of a Commission appointed to Consider a General System of Drainage for the Valleys of Mystic, Blackstone and Charles Rivers, Mass.
A Digest of Decisions of Municipal Interest of the Supreme Judicial Court of Massachusetts, 1804–65.
Catalogue of the City Library, Lowell, Mass.
St. Louis, Mo., Mayor's Message, with accompanying documents. May Session, 1870.
A Pure Water Supply and its Preservation.
Thirteenth Annual Report of the Columbia Oil Company for the year 1874.
Report of the Metropolitan Drainage Commissioners for 1885.
Union Hydraulic Works. Catalogue and Price List.
Provisions of the Ship Railway Concession from the Mexican Republic to James B. Eads, May 9, 1885.
Assainissement de la Seine. Épuration et Utilisation des Eaux d'égout. Vo s. I and II, et Documents Administratifs.
Die Anlage Von Klärbecken und Rieselfeldern zur Reinigung der Abflüsse aus den Städtischen Schwemmsielen.
The Works of the Edgar Thompson Steel Company.

From E. B. Dorsey, London:

Annual Reports of the Board of Directors of the Pennsylvania Railroad Company, from 1883 to 1885.
Lockwood's Builder's and Contractor's Price Book for 1884.
Philips' special large scale War Map of the Soudan, extending to Suakim, on the Red Sea, with enlarged plan of Khartoum, 1885.
The Financial Reform Almanac for 1885.
Whitaker's Almanack for 1885.
International Inventions Exhibition Official Catalogues.

From George Downe, Randwick, Sydney, New South Wales, Australia:

Report by the Commissioner for Railways and Tramways of New South Wales for the year 1884.

From Dyckerhoff & Sohne, Amœneburg, Germany:

Uber die Entwickelung der Deutschen Cement Industrie und über die Methoden der Untersuchung des Cements unter Vorführung der dazu Erforderlische Apparate. Dr. Delbrück. Stettin. 1885.

From N. H. Egleston, Forestry Division, Agricultural Department, Washington, D. C.:

Value and Management of Government Timber Lands, and Distribution of North American Forest Trees.

From G. Howard Ellers, Chicago:

Report of Proceedings of the Illinois State Board of Health. October 29 and 30, 1885.
A Proposed system of Water Supply for the Town of Jefferson, Ill., adjoining the City of Chicago.

From Engineers' Society of Western Pennsylvania, S. M. Wickersham, Secretary, Pittsburgh:

Standard Rail Sections and Fish-Bar Joints.
The Conveyance of Gas.
The Torsion Balance.

From George E. Evans, City Engineer Lowell, Mass.:

Five Photographs of Beacon Street Reservoir, Lowell, Mass.:

From M. N. Forney, New York City:

Report of the Proceedings of the Nineteenth Annual Convention of the Master Car-Builders' Association, held in the Hygeia Hotel, at Old Point Comfort, Va., June 9, 10, 11 and 12, 1885.

From Franklin Institute, Philadelphia:

Report of Examiners of Section XXII, Electric Signalizing and Registering Apparatus, etc.
Report of a Special Committee on Competitive Tests of Dynamo-Electric Machines, and on Mechanical and Electrical Tests of Conducting Wires.
Report of Examiners of Section XII, Gas Engines.

From E. A. Gieseler, Superintendent of Construction, Fourth Light-house District, Philadelphia:

Paper on Tidal Theory and Tidal Predictions (reprinted from *Franklin Institute Journal*, March, 1885.)

From Charles Glackmeyer, City Clerk, Montreal, Canada:

Reports on the Accounts of the Corporation of the City of Montreal, and Reports of the City Officials for the year 1884.

From John C. Goodrich, Jr., New York City:

Can the Temperature of the Atlantic States be Changed? (reprinted from *Scientific American* of October 31, 1885.)

From George S. Greene, Jr., Engineer-in-Chief Department of Docks, New York City:

Annual Report of the Department of Docks for the year ending April 30, 1885, together with the Minutes of the Department for the same year.

From William Hamilton, Superintendent Toronto Water-works, Toronto, Canada:

Annual Report of the City Engineer and Manager of the Water-works, for the year ending December 31, 1883.

From E. W. Harrison, Jersey City, N.J.:

Comparative Schedules showing the Location, Cost of Equipment, Annual Earnings, Operating Cost, Expenses, Taxes, etc., of Railroads in New York, Pennsylvania, Massachusetts, Connecticut and Ohio.

From Gen. W. B. Hazen, Chief Signal Officer U. S. A., Washington, D. C.:

Professional Papers of the Signal Service, No. XVIII.
Thermometer Exposure.
Annual Report of the Chief Signal Officer of the Army to the Secretary of War, for the year 1884.

From Major David Porter Heap, Engineer-Secretary U. S. Light-house Board, Washington, D.C.:

Annual Report of the Light-house Board to the Secretary of the Treasury, for the fiscal year ended June 30, 1885.

From Frank W. Hodgdon, Boston:
Annual Report of the Harbor and Land Commissioners for the year 1885.

From Louis M. Haupt, Philadelphia:
The American Engineering Register, 1885.

From N. H. Hutton, Baltimore:
Annual Report of the Harbor Board for the fiscal year ending December 31, 1885.

From William A. Ingham, Secretary Board of Commissioners Second Geological Survey of Pennsylvania, Harrisburgh:
Second Report of Progress in the Anthracite Coal Region. Part I.
The Geology of Natural Gas in Pennsylvania and New York.
The Product and Exhaustion of the Oil Regions of Pennsylvania and New York.
Report of Cameron, Elk and Forest Counties. Part II.
Report of Huntingdon County, T, 3, and of Delaware C, 5, and Atlas Eastern Middle Anthracite Field.
Grand Atlas, Div. II, Part II; Div. IV, Part I; and Div. V, Part I.

From Institute of Engineers and Shipbuilders. W. J. Millar, Secretary, Glasgow, Scotland:
Transactions. Vol. XXVIII, 1884–85.

From Institution of Civil Engineers, James Forrest, Secretary, London:
Proceedings. Vol. LXXXI, 1884–85, Pt. III.
Proceedings. Vol. LXXXII, 1884–85, Pt. IV.
Brief Subject Index. Vols. LIX to LXXXII, Sessions 1879–80 to 1884–85.
The Signaling of the London and North Western Railway. Arthur Moore Thompson (with an abstract of the discussion upon the paper).
The Semicircular Timber Roof-Truss designed by the late Captain F. Fowke, R. E. Gilbert Richard Redgrave.
Spanish Tidal Flour Mills. Alexander Fairlie Bruce.
The Copper Mines of Butte City, Montana, with an Estimate of the Amount and Cost of Production. David William Brunlon.
On Rivers Flowing into Tideless Seas: illustrated by the River Tiber. William Shelford (with an abstract of the discussion upon the paper).
Erection of a Howe Truss Bridge over the first crossing of the Columbia River, British Columbia, on the Canadian Pacific Railway. Charles Anthony Stoess.
Machinery for the Manufacture of Nitrate of Soda at the Ramirez Factory, Northern Chili. Robert Harvey.
The Iron Bridges on the Hull, Barnsley and West Riding Junction Railway. Frederick Milfrid Scott Stokes.
Abstract of Papers in Foreign Transactions and Periodicals.
A Series of Lectures on the Theory and Practice of Hydro-Mechanics
Corrosion of Metals during Long Exposure in Sea Water. Thomas Andrews.
Mouth of the River Rhone Adolphe Guérard.
Electric Lighting for Railway Trains, William Stroudley.
Removal of Shoals by Propeller-Sluicing on the Columbia River, Oregon, U. S. Harry Hawgood.
Inland Navigation in Europe. Sir Charles A. Hartley.
Forms of Ships. Sir Edward J. Reed.
Tides and Coast Works. Thomas Stevenson.
The Design and Construction of Railway Rolling Stock in Italy. S. Fadda.
The Construction of Locomotive Engines. William Stroudley.
Experiments on the Measurement of Water over Weirs. Bryan Donkin and Frank Salter.
The Oil Wells of Baku. F. Vasilieff.
Heat in its Mechanical Applications: A Series of Lectures delivered at the Institution of Civil Engineers. Session 1883–84.
On the Energy of Fuel in Locomotive Engines. Granville Calyle Cuningham.
The Salt Industry of Stassfurt. Hilary Bauerman.
The Karachi Water-works. James Strachan.
Concrete Building at Simla, India. Walter Smith.
On an Improved Method of Lighting Vessels Under Way at Night. Bradford Leslie.

From M. R. Jefferds, London:
The Panama Canal: Its History, its Political Aspects, and Financial Difficulties. J. C. Rodrigues.
Chemin de fer à Rail unique suréleve: system Lartigue.
Distances, Topographies, and Curved Lines in any way and direction.

From William W. Jefferis, West Chester, Penn:
A New General Atlas exhibiting the five great divisions of the globe. By M. Walter Brun. 1828.
Historical Collections of the State of Pennsylvania for the year 1843.
History of the 97th Regiment Pennsylvania Volunteer Infantry during the War of the Rebellion, 1861–65.

From William A. Jefferis, New York City:
Railroad Gazette from April 1 to December 30, 1871.
Van Nostrand's Eclectic Engineering Magazine, April to December, 1870.
American Edition of the British Encyclopedia. 1817.
Annual Register of the Rensselaer Polytechnic Institute, 1866.
Official Army Register for 1867.
Riverside, Chicago, Ill., in 1871, with a description of its improvements, together with some engravings of views and buildings.
Sixteenth Annual Report of the President and Directors of the Northern Central Railway Company for the year 1870.
Railroad Communication Across the Continent, with an account of the Central Pacific Railroad of California for May, 1867, and February, 1868.
The Union Pacific Railroad from Omaha, Nebraska, across the Continent: its Construction, Resources, Earnings and Prospects for January and May, 1867.
Opinion on the Validity and Sufficiency in Law of the First Mortgage Bonds of the Union Pacific Railroad Company.
An Act to Aid in the Construction of a Railroad and Telegraph Line from the Missouri River to the Pacific Ocean; approved July 1, 1862.
By-Laws of the Board of Directors, together with the Charter of the Wilmington and

Reading Railroad Company, and the supplement for the year 1866.
Report of the Directors of the Wilmington and Reading Railroad Company for the year 1869.
Sixth Annual Report of the Board of Commissioners of Prospect Park, Brooklyn, for the year 1866.
Circular Pamphlet of the Philadelphia Hydraulic Water-works for 1871.
Contract for Cross-Ties Painesville and Youngstown Railroad Company.
Contract of Painesville and Hudson Railroad.
Fairmount Park: Sketches of its Scenery, Waters and History, for the year 1871.

From E. H. Keating, Halifax, N. S :
Report on the Wooden Graving Dock at St. John's, Newfoundland. E. H. Keating.

From Charles Latimer, Cleveland, Ohio:
Atlantic and Great Western Railroad Chart. Financial and Operating Statistics of the Road for a Period of Fourteen years.

From J. Fras. Le Baron, Jacksonville, Fla.:
Constitution and By-Laws of the Southern Society of Civil Engineers, Jacksonville, Fla.

From L. J. Le Conte, Oakland, Cal.:
Are Not Dynamite Catastrophes Intimately Associated with Electric Phenomena? L J. Le Conte. From Transactions of the Technical Society of the Pacific Coast, August, 1885.

From Capt. D. A. Lyle, Ordnance Department U. S. A., Boston:
Annual Report of the Operation of the United States Life Saving Service for the fiscal year ending June 30, 1884.

From Manchester Ship Canal Company, Manchester, England:
Manchester Ship Canal. Description of the Project now before Parliament, January, 1884.
Reply of Mr. Pember, Q. C., on behalf of the Promoters of the Bill.
A Reply to Mr. A. Provand's Address. Criticism by a Supporter of the Canal.
How the Railway Companies are Crippling British Industry and Destroying the Canals.
Some Local Considerations in relation to the proposed Manchester Ship Canal.
Engineers' Reports and Reports of the Provisional Committee.
The London Daily and Periodical Press on the Question.
Map of the Manchester Ship Canal, with a Description of the Plans prepared for the Session 1885.

From Charles C. Martin, Brooklyn:
Report of the Trustees of the New York and Brooklyn Bridge for the year ending December 1st, 1885.

From Robert K. Martin, Chief Engineer Water Department, Baltimore, Md.:
Report of the Water Department of the City of Baltimore, for the years 1864, 1865, 1867, 1868, 1870, 1872 to 1874, 1877, 1879, 1880, 1884.

From C. A. McNeale, Secretary St. Paul Chamber of Commerce St. Paul, Minn.:
Annual Report of the St Paul Chamber of Commerce for the year ending December 31st, 1884.

From A. Marichal, Philadelphia:
Manual of the Curvograph. A. Marichal, C. E.

From Mining Institute of Scotland James Barrowman, Secretary, Hamilton:
Official Catalogue of Exhibits of the Mining Exhibition held at Burnbank Drill Hall, Great Western Road, Glasgow, under the auspices of the Mining Institute of Scotland, 1st till 24th September, 1885.

From Gratz Mordecai, New York City:
A Report on the Terminal Facilities for Handling Freight for the Railroads entering the Port of New York.
Map of New York City and surroundings. Illustrating and accompanying a report on the Terminal Facilities for Handling Freight of the Railroads entering the Port of New York for 1885.

From George S. Morison, New York City:
Lithographed Drawing of Deck Span of New Omaha Bridge, Central Pacific Railroad.
Specifications for Superstructure of New Bridge across the Missouri River at Omaha, Neb.
Report of the President and Directors of the Ohio and Mississippi Railway Company to the Stockholders for the year ending June 30, 1885.
The Eighth, Eighteenth, Twentieth, Twenty-first, Twenty-second and Twenty-third Annual Reports of the Maine Central Railroad Company for the years 1878-80 to 1884.

From New York State Board of Health, Albany:
Monthly Bulletin for August, September, October, November and December, 1885.

From Prof. Simon Newcomb, U. S. N., Supt. American Ephemeris and Nautical Almanac, Washington, D. C.:
The American Ephemeris and Nautical Almanac, Washington, D. C.
Astronomical Papers prepared for the use of the American Ephemeris and Nautical Almanac, Vol. II, Parts III and IV; and Vol. III, Part IV, 1885.

From Gen John Newton, Chief of Engineers U. S. A., Washington, D. C.:
Official Army Register for January, 1886.
Report from the Mississippi River Commission recommending an immediate appropriation of $50,000 for the general work of surveys.
Report of the Missouri River Commission recommending an immediate appropriation.
Report of the Joint Commission for the Completion of the Washington Monument.
Report relating to Causeways, Bridges, etc., in process of erection, that may interfere with navigation.
Advertisements, Specifications and Proposals, as follows;
Ice Pier at Point Pleasant, W. Va.
Improving Harbor at Cleveland, Ohio.
Toledo Harbor, Ohio.
Dredging at Ogdensburg Harbor, New York
Removal of Wrecks in the Delaware River.
Proposals for Rubble Stone.

Furnishing Rip-rap Granite for the Eastern Jetty at Nantucket, Mass, and placing the same in the Jetty.
Proposals for the Weighing and for the Purchase of Iron removed from the Wreck of the Steamer Nankin, New York Harbor.
Removal of the Wreck of the Steamship Perkwinen.
Replacing the Concrete and Wooden Platforms for Heavy Guns by Concrete Platforms for the same Guns, at Forts Jackson and St. Philip, La.
For Supplies and Material.
Removal of the Wreck of the Steamer Dictator, now laying in Harbor at Tampa, Florida.
Removing Obstructions in East River and Hell Gate, New York.
Timber for Gates and Wickets of Lock and Dam No. 6.
Removal of the Wreck of the Sunken Scow now lying in Harbor at Tampa, Florida.
Fairport Harbor, Ohio.
Repairs of Bridge over the Moat at Fort Montgomery, N. Y.

From New York Meteorological Observatory, Department of Public Parks, Dr. Daniel Draper, Director, New York City:

Abstract of Registers from Self-recording Instruments, October and November, 1885.

From William Ripley Nichols, Boston:

A Study of the Relative Poisonous Effects of Coal and Water Gas.
An Address before the Section of Chemistry of the American Association for the Advancement of Science at Ann Arbor, August, 1885.

From Richard B. Osborne, Philadelphia:

Select Plans of Engineering Structures for Railroads and Highways.

From W. B. Parsons, Jr., New York City:

The New York District Railway Company, with the Opinions of the Press, Letters, etc.

From E. Pontzen, Paris, France:

Étude practique sur la Cement de Portland Fabrication, Proprietes, Emploi. E. Candlot.
Les Chemins de Fer Russes, 1857-62.

From J. W. Powell, Director United States Geological Survey, Washington, D. C.:

On the Organization of Scientific Work of the General Government.

From George W. Rafter, Rochester, N.Y.:

Final Report on Construction of the Fredonia Water-works at Fredonia, Chautauqua County, N. Y. G. W. Rafter.

From Rektor Technischen Hochschule, Hanover, Germany:

Catalogue of the Library of the Technical High School, Berlin, Germany.

From Henry H. Remfoy, Calcutta, India:

Pamphlet on Patents. Information and Forms for India, Ceylon, Straits Settlements and Hong Kong.

From John A. Russell, San Francisco, Cal.:

San Francisco Municipal Reports for the Fiscal Year 1884-85, ending June 30th, 1885.

From D. C. Sanford, New Haven, Conn.:

Proceedings of the Connecticut Association of Civil Engineers and Surveyors, held at Middletown, Conn., September 25th, 1885.

From Major Alfred F. Sears, Brockton, Mass.:

Paper on the Glover System. Disposal of the Sewage of Brockton, 1885.

From Hon. J. B. Shaw, New York City:

New York Supreme Court. In the Matter of the Petition of the New York Cable Railway Company, Vol. I., containing Record of Proceedings before Supreme Court Commissioners, including Articles of Associations and Map of Petitioner's Routes of Railway.
Objectors' case before Guy R. Pelton, William C. Traphagen and Leroy B. Crane, Vols. I and II.
Proceedings of Commissioners of Rapid Transit of New York for 1884.
Report of Commissioners.
Vols. I and II. General Term, First Department. In the Matter of the Petition of the New York Cable Railway Company. Vol. I. Record of Proceedings, Vol. II, Petitioners' Proofs.
Concluding Argument by Charles P. Shaw.

From Massachusetts State Board of Health, Lunacy and Charity, Boston:

Sixth Annual Report of the State Board of Health, Lunacy and Charity of Massachusetts for 1884-85.

From Prof. George F. Swain, Boston:

Twenty-first Annual Catalogue of the Officers and Students of the Massachusetts Institute of Technology, with a statement of the Courses of Instruction for 1885-86.

From Hon. E. Sweet, State Engineer and Surveyor, Albany, N. Y.:

Report of Canal Commissioners, State of New York, for 1876.
Annual Financial Report of Auditor for 1880.
Annual Report of Auditor on Tolls, Trade and Tonnage of the Canals for 1854, 1873, 1881.
Annual Report of State Engineer and Surveyor on the Canals for 1882.

From Robert Surtees, Ottawa, Canada:

Annual Report of the Water-works Committee for the year ending October 31, 1885, with Official Report.

From William F. Switzler, Chief of Bureau of Statistics, Washington, D. C.:

Annual Report and Statements of the Chief of the Bureau of Statistics on the Foreign Commerce and Navigation, Immigration and Tonnage of the United States, for the fiscal year ending June 30, 1885.

From Union Bridge Company, New York City:

Photograph of Kentucky and Indiana Bridge.
Photograph of the Double Cantilever Bridge over the Ohio River, between Louisville and New Albany, now being erected by the Union Bridge Company.

From U. S. Coast and Geodetic Survey, Washington, D. C.

Report of the Superintendent of the U. S. Coast and Geodetic Survey, showing the progress of the work during the fiscal year ending with June, 1884.

From United States Geological Survey, Washington, D. C.:

Mineral Resources of the United States, 1883 and 1884.

Bulletins of the United States Geological Survey, Nos. 7–23.

From United States Naval Institute, Annapolis, Md.

Proceedings, Vol. XI, No. 4.

From Irving S. Upson, Librarian Rutgers College, New Brunswick, N. J.:

Catalogue of the Officers and Students of Rutgers College 1885–86.

From D. Van Nostrand, New York City:

A Practical Treatise on Hydraulic Mining in California. Aug. J. Bowie, Jr.

From George W. Van Siclen, New York City:

Guide to Buyers and Sellers of Real Estate; how to Draw a Contract, etc.

From Prof. George L. Vose, Boston:

A Sketch of the Life and Works of Loammi Baldwin, Civil Engineer.

From Welton & Bonnett, Waterbury, Conn.:

Nineteenth Report of the Board of Water Commissioners of the City of Waterbury, Conn., for the year ending December 31st, 1885.

From A. M. Wellington, New York City:

Profile and Tracing of Georgetown, Breckenridge and Leadville Railway; also statement published in *Railroad Gazette* of November 27th, 1885.

From Edmund B. Weston, Providence, R. I.

Bulletin of the New England Meteorological Society for July, August, September, October, November and December, 1885.

From W. Howard White, New York City:

Railroad Gazette for July, August, September and October, 1879.

Report upon the Contemplated Metropolitan Railroad of the City of New York. A. P. Robinson.

From Albert Williams, Jr., Chief of Division of Mining Statistics and Technology United States Geological Survey, Washington, D. C.

Statistics of the Production of the Precious Metals. By Clarence King. 1881.

Placer Mines and Mining Ditches.

The Mining of Gold and Silver.

Popular Fallacies regarding Precious Metals.

Mining Geology of the Eureka District, Nevada. J. S. Curtis.

Geological Sketches of the Precious Metal Deposits of the Western United States. S. F. Emmons.

Abstract of a Report upon the Geology and Mining Industry of Leadville, District of Colorado. S. F. Emmons.

Mineral Products of the United States, 1882 and 1884.

Chart showing the Mineral Products of the United States in the calendar years 1882, 1883 and 1884.

From Prof. De Volson Wood, Hoboken, N. J.:

The Luminiferous Æther.

From William E. Worthen, New York City:

Record of Meeting of Common Council of the City of Albany, November, 30th, 1885, containing report of William E. Worthen on Sources of Additional Water Supply for Albany.

From Col. Carroll D. Wright, Chief of Bureau of Statistics of Labor, Boston:

Fifth, Seventh, Tenth and Sixteenth Annual Reports of the Bureau of Statistics of Labor. Massachusetts.

Statistics of Drunkenness and Liquor Selling under Prohibitory and License Legislation, 1874 and 1877.

Intemperance and Crime.

Fall River, Lowell and Lawrence.

The Canadian-French in New England.

The Working Girls of Boston.

Employers' Liability for Personal Injuries to their Employees.

Industrial Conciliation and Arbitration. Complied by Carroll D. Wright. Boston, 1881.

Labor Laws of Massachusetts. Compiled from Public Statutes. 1884.

Reports of the 1st, 2d and 3d Annual Sessions of the National Convention of Chiefs and Commissioners of Bureaus of Statistics of Labor in the United States. 1883, 1884 and 1885.

From Charles G. Yale, Secretary Technical Society of the Pacific Coast, San Francisco, Cal.:

Transactions, Vol. I, March to December, 1884; and Vol. II, January to September, 1885; and Record of Meetings for September 5th and October 3d, 1884.

From other sources:

Safety Electric Power Company. Daft System.

Forty-fifth Annual Announcement of Lectures and Catalogue University of the City of New York, Session 1885–86.

Report of the Proposed Extension of the Water-works East of Rockville Centre.

Artillery and Engineering Review for December, 1885. Rome, Italy.

Ingegneria (Elettriata-strade ferate Tramways Idraulica Miniere, c. c. c.) Architectura Decorazione ed ornamentazione. 1886.

Ueber den Betrieb auf den Canälen in Nord America.

The Free Press, London, England:

Vol. V. 1857.

Vol. VI. July to December, 1858. Incomplete.

Vols. VII and VIII. January 26th, 1859, to December 5th, 1860.

Vols. IX and X. January 1st, 1861, to December 3d, 1862.

Vols. XI, XII and XIII. January, 1863, to December, 1865.

The Diplomatic Review, London, England:

Book IV, Vols XIV to XVIII. January, 1866, to October, 1870.

LIST OF MEMBERS.

ADDITIONS.

MEMBERS.

		Date of Election
ECKERT, EDWARD WILLIAM	Engineer Massillon Bridge Co., Massillon, Ohio	Feb. 3, 1886.
KILLEBREW, SAMUEL	Saltillo, Coahuila, Mexico	Sept. 2, 1885.
MILLS, JAMES ELLISON	Quincy, Plumas Co., Cal	Feb. 3, 1886.
SCHERZER, ALBERT JOHN	(Care W. H. Harned), 206 South 4th st., Philadelphia, Pa	Jan. 6, 1886.
SPENCER, SAMUEL	Vice-President Baltimore and Ohio R. R., Baltimore, Md	Sept. 2, 1885.
WRIGHT, EDWARD THOMAS	County Surveyor, Los Angeles, Cal	Feb. 3, 1886.

ASSOCIATES.

BURROWS, GEORGE LORD	Saginaw, Mich	Feb. 3, 1886.
RICKETTS, PALMER CHAMBERLAINE	17 First st., Troy, N. Y.	Feb. 3, 1886.
TOMKINS, CALVIN	387 South st., New York City	Jan. 6, 1886.

FELLOW.

COOPER, EDWARD	17 Burling slip, New York City	Dec. 10, 1885.

CHANGES AND CORRECTIONS.

MEMBERS.

ANDREWS, DAVID H	70 Kilby st., Boston, Mass.
BURNET, GEORGE, JR	Box 535, St Louis, Mo.
COMSTOCK, CYRUS B	Lt.-Col. Corps of Engineers, Bvt. Brig.-Gen., U. S. A., Willets' Point, Whitestone P. O., N. Y.
DRAKE, WILLIAM A	(Care Engineer Department), Atchison, Topeka and Sante Fé R. R., New Kiowa, Kansas.
GOLAY, PHILIP	Vevay, Indiana.
HINCKLEY, JOHN F	Chief Engineer Paris and Great Northern Ry., Paris, Texas.
KITTREDGE, GEORGE W	Engineer Maintenance of Way, Cincinnati and Muskingum Valley Ry., Zanesville, Ohio.

NICHOLS, O. F.....Contractor, Westerly, R. I., and Chief Engineer Water-works, Westerly, R. I.
NICOLLS, WILLIAM J.....313 Walnut st., Philadelphia, Pa.
NOBLE, ALFRED.....(Care D. Wallace), 24 Alexandrine ave. West, Detroit, Mich.
OSGOOD, JOSEPH O.....(Care Toledo, Cincinnati and St. Louis R. R.), Toledo, Ohio.
PAINE, CHARLES.....Vice-President Philadelphia Co., 933 Penn ave., Pittsburgh, Pa.
ROGERS, ALBERT B.....Faribault, Rice Co., Minn.
SMITH, ISAAC W.....Engineer Portland Water Committee (Box 42), Portland, Oregon.
SMITH, JARED A.....Major Corps of Engineers, U. S. A., Portland, Maine.
STAATS, ROBERT P.....361 West 20th st., New York City.
WURTELE, ARTHUR S. C.....165 Niagara st., Buffalo, N. Y.

JUNIORS.

FRANCIS, GEORGE B.....235 West 128th st., New York City.
SCHAUB, JULIUS W.....(Care Dominion Bridge Co.), Montreal, Canada.

RESIGNATIONS.

MEMBERS.

DABNEY, FREDERICK Y.....Jan. 31, 1886.
ROEBLING, WASHINGTON A.....Feb. 5, 1886.

American Society of Civil Engineers.

PROCEEDINGS.

Vol. XII.—March, 1886.

MINUTES OF MEETINGS.

(Abstract of such as may be of general interest to members.)

OF THE SOCIETY.

March 3d, 1886.—The Society met at 20 o'clock, W. Howard White, Director Am. Soc. C. E., in the Chair. The following candidates were elected as Members: Danforth Hurlbert Ainsworth, Newton, Iowa; Decatur Axtell, Richmond, Va.; William Herbert Burr (elected Junior, June 3, 1874; elected Associate, May 5, 1880), Phœnixville, Pa.; Albert Lucius, Brooklyn, N. Y.; Robert Edwin Peary, Washington, D. C.; Charles de la Cherois Burdon, Van Buren, Arkansas; James Robert Wardlaw, New York City. As Associate: Clayton Colman Hall, Baltimore, Md. As Junior: George Washington Vaughan, Steubenville, Ohio.

The election as Fellow of the Society of Edward Cooper, New York City, was announced.

A paper by Fred Brooks, M. Am. Soc. C. E., on Thermometer Scales, was read and discussed.

A paper, by H. V. Hinckley, M. Am. Soc. C. E., on Errors in Railroad Levels, was read and discussed.

March 17th, 1886.—The Society met at 20 o'clock, Vice-President Thomas C. Keefer in the Chair.

A synopsis of a paper by Desmond FitzGerald, M. Am. Soc. C. E., on Evaporation was given by the author, and the subject was discussed.

A discussion by George Downe, M. Am. Soc. C. E., on English and American Railroads Compared, was read.

OF THE BOARD OF DIRECTION.

March 10th, 1886.—Applications were considered. The time and other details of the Convention to be held at Denver were discussed.

The receipt was announced from Major F. H. Parker, Corps of Ordnance, U. S. A., commanding Watertown Arsenal, of the results of tests to determine frictional resistance of steel between shrinkage surfaces.

The tests were ordered published in the Proceedings.

MEMOIRS OF DECEASED MEMBERS.

JOHN GRIFFEN, M. Am. Soc. C. E.

DIED JANUARY 14TH, 1884.

John Griffen was born in Westchester County, New York, in the year 1812. Before he had completed his first year, death deprived him of his father. Thus his education devolved upon his mother until his fourteenth year, when he commenced attending a Friends' Boarding School in Dutchess County, New York. Upon completing his education he entered the mercantile establishment of an uncle in the City of New York, and continued there until his majority. His talents for engineering and mechanical pursuits were developed in the iron-works and nail factory of R. C. Nichols, at Norristown, where he was employed as bookkeeper in 1843. Under his direction the iron-works of Moore & Hooven, of the same place, were erected, and while thus engaged, he conceived and successfully applied a novel method of using the waste heat from the heating and puddling furnaces for generating the steam necessary to run the engines. The works of Reeves, Abbott & Co. were also constructed by him, and afforded additional opportunity for the display of his remarkable executive abilities. Until 1856 he remained in the employ of this Company in the capacity of Superintendent, during which time he introduced the governor for controlling the speed of steam engines used in rolling iron, which was regarded as a desideratum of the highest importance. Although numerous contrivances connected with the manufacture of iron proceeded from his fruitful brain, his invention for making wrought-iron cannon was sufficient to place his name high upon the roll of American inventors. After repeated experiments by the Government to test the strength of this ordnance, it was accepted as one of great value, and many hundreds of these guns were made by the Phœnix Iron Company, and, known as the "Griffen Gun," were used during the War of the Rebellion.

From Safe Harbor, he went to Phœnixville to take charge of the celebrated iron-works of that place, where he remained until 1862. Other inventions of his followed which are regarded of great importance in facilitating the operations connected with the iron industry, notable among which may be mentioned a machine for rolling the large wrought-iron beams used in building, for which he obtained a patent in 1857. This continues in successful operation. For many years he rolled the largest beams in the world.

In 1862, he engaged to erect the Buffalo Union Iron-works, which, although built at so early a period, are classed among the best in this country.

The position of civil and mechanical engineer having been tendered him by the Phœnix Iron Company in 1867, it was accepted, and eighteen months later he was again placed in charge. During his incumbency he erected the new and large works for that company.

In 1837 he was married to Esther, daughter of Reuben Leggett, of New York, by whom he had five children, of whom only one survives. Two years after the death of his first wife he married her sister, by whom he had five children, four of whom are living. Robert, the eldest son, was in the United States Navy, having graduated at the Naval School. He lost his life by yellow fever while in the service of his country.

Mr. Griffen was one of the directors of the Phœnixville Iron Company, and also a member of the firm of Clarke, Reeves & Co., the celebrated bridge-builders. Although devoted to business pursuits he found time to perform the duties appertaining to positions of public usefulness. In 1857 he was elected Burgess of Phœnixville, and he afterwards became a member of the School Board. While occupying that important position he was largely instrumental in advancing common school education, and in improving the school buildings.

Mr. Griffen was a man whose character impressed itself on all whom he met. He was honest, straightforward, and upright in all his ways. He was a good citizen, a good husband, a good father, and a good friend.

His memory was wonderful for its extent and its accuracy; what he knew he knew thoroughly, and he never pretended to know more than he did know.

After his visit to Europe in 1878, where he saw all the great iron and steel manufactories, he delighted to tell of his experience, and draw just comparisons between their methods and our own, with that absolute fairness which so much distinguished him. During his long and painful illness his intellectual vigor never forsook him, and he died as he had lived, a good Christian and an honest man.

Mr. Griffen became a Member of the American Society of Civil Engineers April 15th, 1868.

REDMOND JOHN BROUGH, M. Am. Soc. C. E.

Died July 21st, 1883.

Redmond John Brough, late City Engineer of Toronto, Ontario, was the eldest son of the late Secker Brough, Esq., Judge of the County Court of the County of Huron. After a short preparation in the University of Toronto, he began active practice in 1870, under Mr. Thomas Weatherall, C. E., on the Ontario Government Survey for the drainage of a portion of the County of Huron. In June of the same year he received an appointment on the engineering staff of the Great Western Railway of Canada, and was engaged in the preliminary and location surveys of the Canada Air Line Railroad. In November he was appointed assistant engineer on the western division of that road, which position he held up to the date of the completion of construction in July, 1873. He was then put in charge of the work of double-tracking a section of the main line of the Great Western Railway. On the completion of this work in November, 1873, he received, on the recommendation of Mr. John Kennedy, then Chief Engineer of the Great Western Railroad, an appointment as assistant engineer on the Toronto Water-works, under Mr. P. A. Peterson, Chief Engineer, which position he held up to 1876. At that date Mr. Peterson resigned and Mr. Brough was appointed resident engineer in charge of the construction of the works under the late City Water Commission. He was soon after appointed Chief Engineer and Manager of the Water-works. On the resignation of Mr. Frank Shanly, in 1878, he was appointed to succeed that gentleman as City Engineer of Toronto, and held this position up to the time of his death. On the 12th of July, 1883, while inspecting a portion of the city works, he was thrown from his carriage, breaking his thigh and receiving serious internal injuries, which resulted in his death, after a painful illness, on the 21st of the same month. He was in his thirty-seventh year at the time of his death, which closed a career which had promised to be more than usually successful. His abilities as an engineer were of a high order, and were united with good judgment and strict integrity. He enjoyed the respect and good-will of all who came in contact with him, and died sincerely mourned by many friends.

He was an Associate Member of the Institution of Civil Engineers, London, and a Member of the American Society of Mechanical Engineers.

He was admitted as a Member of the American Society of Civil Engineers September 1st, 1880.

LIST OF MEMBERS.

ADDITIONS.

MEMBERS. Date of Election.

AINSWORTH, DANFORTH HURLBERT..Newton, Iowa .....March 3, 1886.

AXTELL, DECATUR ....Receiver Richmond and Alleghany R.R., Richmond, Va. March 3, 1886.

BURR, WILLIAM HERBERT.....(Elected Junior, June 3, 1874, elected Associate, May 5, 1880) Assistant to Chief Engineer Phœnix Bridge Co., Phœnixville, Pa.....March 3, 1886.

LUCIUS, ALBERT.....Chief Engineer Brooklyn, Bath and West End R. R., 211 Eleventh st., South Brooklyn, N. Y.....March 3, 1886.

PEARY, ROBERT EDWIN .....Civil Engineer, U. S. N., Washington, D. C.....March 3, 1886.

PURDON, CHARLES DE LA CHEROIS..Engineer in charge Arkansas River Bridge, St. Louis and San Francisco Ry., Van Buren, Ark.....March 3, 1886.

WARDLAW, JAMES ROBERT.....Assistant Engineer, Department Public Works, 31 Chambers st., New York City.....March 3, 1886.

ASSOCIATE.

HALL, CLAYTON COLMAN.....Actuary to the Insurance Department, State of Maryland, Baltimore, Md.....March 3, 1886.

JUNIOR.

VAUGHAN, GEORGE WASHINGTON....Supervisor Sub-Division 3, Pittsburgh, Cincinnati and St. Louis Ry., Steubenville, Ohio..... .....March 3, 1886.

CHANGES AND CORRECTIONS.

CORRESPONDING MEMBER.

FOX, SIR DOUGLAS.....2 Victoria Mansions, Victoria st., Westminster, S. W., London, England.

MEMBERS.

APPLETON, ELLERY C.....Resident Engineer Burlington and Missouri River R. R. in Nebraska, Ashland, Neb.

CROWELL, J. FOSTER.....Engineer of Construction Pennsylvania R. R., 131 Maplewood ave., Germantown, Philadelphia, Pa.

DORAN, FRANK C.....Richmond, Indiana.

GREENE, GEORGE S., JR.....Engineer-in-Chief Department of Docks, Pier A, foot of Battery Place, North River, New York City.

HARRIS, WILLIAM P.....581 Washington ave., Brooklyn, N. Y.

HEGEMAN, WILLIAM W.....Engineer and Superintendent Heman Clark & Co., Contractors, Kansas City Extension, Chicago, Milwaukee and St. Paul Ry., Ottumwa, Iowa.

MOORE, CHARLES E.....San Jose, Cal.

NICHOLS, WILLARD A.....First Assistant Engineer Department of Docks, Pier A, foot of Battery Place, North River, New York City.

TOWLE, STEVENSON.....Consulting Engineer, 25 Chambers st., New York City.

VAUGHAN, F. W.....President Louisville Bridge and Iron Co., Consulting Engineer Louisville and Nashville R. R., Louisville, Ky.

JUNIORS.

HAVILAND, ARTHUR.....City Engineer's Office, San Antonio, Texas.

RAYMOND, CHAS. WARD.....(Care Sooysmith & Co.) 52 Montauk Block, Chicago, Ill.

THE NORMAN MEDAL.

CODE OF RULES FOR ITS AWARD.

I.—Competition for the Norman Medal of the American Society of Civil Engineers shall be restricted to members of the Society.

II.—There shall be one gold medal, and only one, struck for each and every fiscal year of the Society, and awarded as hereinafter provided. The dies therefor shall be with the Superintendent of the United States Mint at Philadelphia, in trust exclusively for the above purpose. Such medal shall be of a cost equal to the annual interest received upon $1 000 of the Consolidated Stock of the City of New York, Certificate No. 179, of the additional new Croton Aqueduct Stock of the City of New York, authorized by an Act of the Legislature of the State of New York, Chap. 230, passed April 15th, 1870, dated November 17th, 1873, now held in trust by the Treasurer of this Society, and so held solely for this purpose, and shall be executed upon his order.

III.—All original papers presented to the Society by members of any class, during the year for which the medal is awarded, shall be open to the award, provided that such papers shall not have been previously contributed in whole or in part to any other association, nor have appeared in print prior to their publication by the Society, nor have been presented to the Society in any previous year.

IV.—The Board of Censors to award the medal shall consist of three members of the Society, to be designated by the Board of Direction. The Secretary of the Society shall act as Secretary to the Board of Censors.

V.—The medal shall be awarded to such paper as the said Board shall judge to be worthy of special commendation for its merits as a contribution to engineering science, not merely relatively as compared with others presented during the same year, but as exhibiting the science, talent or industry displayed in the consideration of the subject treated of, and for the good which may be expected to result from the discussion and the inquiry.

VI.—In case no paper presented during the year shall be deemed of sufficient value to receive an award, the amount of the interest of the fund for that year shall be expended by the Board of Direction in the purchase of books, to be offered as a premium for the second best paper in the next year in which more than one paper of sufficient value may be presented.

VII.—The medal year shall terminate on the first day of August, and the award shall be announced at the annual meeting.

VIII.—The Treasurer of this Society shall cause the medal to be prepared and delivered to, or deposited to the order of, the successful competitor, within two months after the annual meeting at which the same shall have been awarded.

THE ROWLAND PRIZE.

CODE OF RULES FOR ITS AWARD.

Not more than one prize shall be awarded each year for papers presented during the year. The year shall terminate on the first day of August, and the award shall be announced at the annual meeting in January.

The prize shall consist of fifty dollars in cash.

The award shall be made by a committee consisting of the Secretary and two members of the Society, to be appointed by the Board of Direction.

The prize shall be awarded to such paper as the committee deem most worthy of such recognition, the preference being given to papers describing in detail accomplished works of construction, their cost and manner of execution, and the errors in design and execution.

American Society of Civil Engineers.

PROCEEDINGS MARCH, 1886.

REPORT OF MECHANICAL TESTS

MADE WITH THE

U. S. TESTING MACHINE,

CAPACITY 800,000 POUNDS,

AT WATERTOWN ARSENAL, MASS.,

MARCH 2D, 1886,

— FOR —

THE ORDNANCE DEPARTMENT, U. S. A., WASHINGTON, D. C.

These Reports are furnished by direction of General S. V. BENÉT, *Chief of Ordnance, U. S. A., for publication in the Proceedings of the American Society of Civil Engineers.*

TESTS BY COMPRESSION.

FRICTIONAL RESISTANCE OF STEEL HOOPS SHRUNK ON STEEL TUBES.

The hoops and tubes were received at Watertown Arsenal in their assembled state, having been prepared and shrunk together at West Point Foundry under the supervision of Lieut. R. Birnie, Ordnance Department, U. S. A.

The estimated temperature of the 3-inch hoop when taken from the furnace to assemble was 470 degrees Fah., that of the 4-inch hoop 515 degrees Fah.

At Watertown Arsenal the accessible diameters were measured before unhooping, and again after unhooping; the several diameters making equal angles with each other. The unhooping was done by forcing the hoops from the tubes in the direction of their axes.

One end of a tube rested against the flat platform of the testing machine, a cast-iron ring being used between the opposite platform and the hoop.

In the details of the tests are shown the apparent movement of the hoops on the tubes during the progress of the loading, up to the maximum resistance, and afterwards the diminishing loads on the hoops at intervals until they were wholly removed from the tubes.

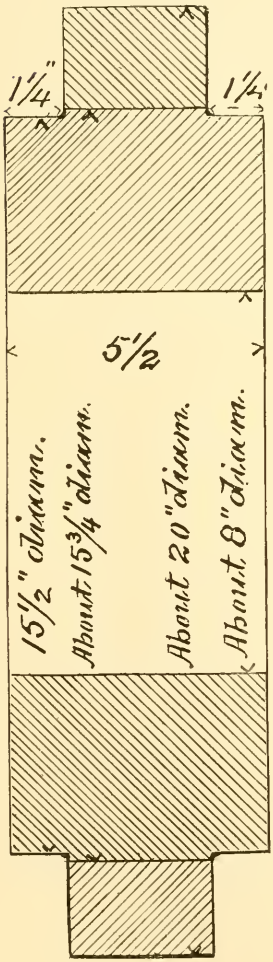
Intervals of rest of longer or shorter duration were allowed, and the effect on the frictional resistance observed.

The hoops did not slip over the tubes with a smooth, continuous movement, but with a series of sudden slips or throbs, during which there were fluctuations of the loads.

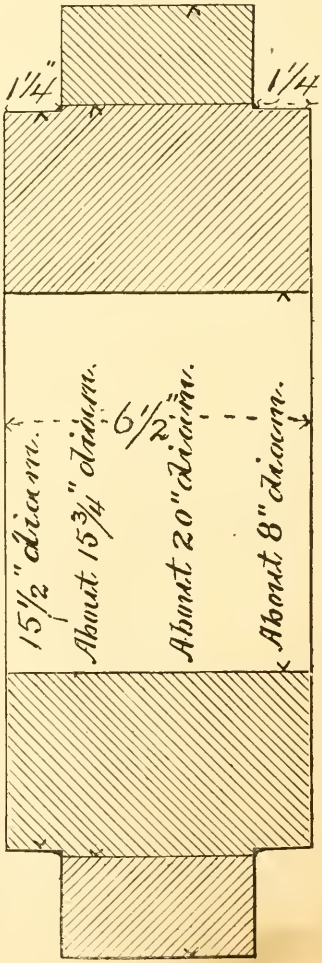
Water was sprinkled upon the assembled parts while they were hot, which is thought to account for its presence on the frictional surfaces after unhooping.

DIMENSIONS OF HOOPS.

3-inch Hoop.



4-inch Hoop.



Difference in shrinkage diameters after unhooping—
3-inch hoop and tube..... 0.016434 inch.
4-inch hoop and tube..... 0.016350 inch.

Maximum frictional resistance found—
3-inch hoop and tube..... 265 800 pounds.
4-inch hoop and tube..... 404 100 pounds.

EXTERIOR DIAMETERS OF 3-INCH HOOP.

Before Unhooping.

Distance from Top.	Diameters.				Means.
	1	2	3	4	
Inches.	Inches.	Inches.	Inches.	Inches.	Inches.
0.5	20.0165	20.0164	20.0156	20.0158	20.016075
1.5	20.0164	20.0162	20.0153	20.0152	20.015775
2.5	20.0159	20.0158	20.0146	20.0147	20.015250

Mean.....20.0157

After Unhooping.

0.5	20.0042	20.0043	20.0041	20.0042	20.004200
1.5	20.0041	20.0038	20.0038	20.0038	20.003875
2.5	20 0036	20.0034	20.0033	20.0033	20.00340

Mean..... 20.003825
Restoration..... 0.011875 inch.

MEASUREMENTS OF BORE OF TUBE WITH 3-INCH HOOP.

Before Unhooping.

0.50	7.9946	7.9953	7.9952	7.9954	7.995125
2.75	7.9960	7.9961	7.9957	7.9957	7.995875
5.00	7.9968	7.9969	7.9970	7.9968	7.996875

Mean 7.995958

After Unhooping.

0.50	7.9970	7.9971	7.9971	7.9975	7.997175
2.75	7.9980	7.9984	7.9980	7.9985	7.998225
5.00	7.9988	7.9988	7.9988	7.9988	7.998800

Mean..... 7.998066 +
Mean restoration 0.002108 + inch.

Exterior Diameters of 4-inch Hoop.

Before Unhooping.

Distance from Top.	Diameters.				Means.
	1	2	3	4	
Inches.	Inches.	Inches.	Inches.	Inches.	Inches.
0.5	20.0246	20.0246	20.0246	20.0246	20.024600
2.0	20.0238	20.0238	20.0238	20.0237	20.023775
3.5	20.0226	20.0226	20.0226	20.0222	20.022500

Mean..... 20.023625

After Unhooping.

0.5	20.0137	20.0138	20.0142	20.0142	20.013975
2.0	20.0124	20.0123	20.0128	20.0128	20.012575
3.5	20.0109	20.0112	20.0112	20.0110	20.011075

Mean..... 20.012541 +
Restoration..... 0.011084 + inch.

Measurements of Bore of Tube with 4-inch Hoop.

Before Unhooping.

0.50	7.9919	7.9919	7.9919+	7.9918	7.991875
3.25	7.9903+	7.9903	7.9902	7.9903	7.990275
6.00	7.9923	7.9921+	7.9922	7.9921+	7.992175

Mean..... 7.991441 +

After Unhooping.

0.50	7.9945	7.9945+	7.9941	7.9944	7.994375
3.25	7.9931	7.9933	7.9930	7.9930	7.993100
6.00	7.9947	7.9947	7.9946	7.9944	7.994600

Mean..... 7.994025 inches.
Mean restoration 0.002584 inch.

Interior Diameters of Hoops after Unhooping.

3-inch Hoop.

Distance from Top.	Diameters.				Means.
	1	2	3	4	
Inches.	Inches.	Inches.	Inches.	Inches.	Inches.
0.5	15.7463	15.7462	15.7463	15.7463	15.746275
1.5	15.7451	15.7450	15.7452	15.7452	15.745125
2.5	15.7459	15.7460	15.7459	15.7461	15.745975

Mean..... 15.745791 inches.

4-inch Hoop.

0.5	15.7456	15.7459	15.7462+	15.7460	15.745925
2.0	15.7458	15.7462	15.7468	15.7462	15.746250
3.5	15.7459	15.7461	15.7462	15.7462	15.746100

Mean..... 15.746092 inches.

Exterior Diameters of Tubes after Unhooping.

Tube with 3-inch Hoop.

0.5	15.7625	15.7626	15.7627	15.7625	15.762575
1.5	15.7620	15.7620	15.7621	15.7620	15.762025
2.5	15.7621—	15.7620	15.7621+	15.7621	15.762075

Mean..... 15.762225 inches.

Tube with 4-inch Hoop.

0.5	15.7617	15.7620	15.7620	15.7620	15.761925
2.0	15.7623	15.7624	15.7625	15.7624	15.762400
3.5	15.7628	15.7623	15.7631	15.7628	15.763000

Mean..... 15.762442 inches.

FRICTIONAL RESISTANCE BETWEEN TUBE AND 3-INCH HOOP.

Details.

APPLIED LOADS.	MOVEMENT	TIME.	REMARKS.
Pounds.	Inches.		
50 000	0	....	Initial load.
89 000	0		
100 000	.0006	....	Micrometer measurements were taken between the hoop and face of holder of testing machine. Hence the apparent movement of the hoop on the tube includes the compression of the cast-iron fixture.
150 000	.0014		
200 000	.0024		
220 000	.0025		
240 000	.0035		
245 000	.0038		
250 000	.0030		
260 000	.0030	....	Maximum frictional resistance.
265 800	.....	....	Sudden slip of hoop on tube.
.....	.0504	....	After the slip.
132 000	.....	....	Continues the movement.
130 400	.1138		
Micrometer measurements now taken from holder to holder.			
128 000	.1138	....	Rested 10 minutes.
137 000	.1140		
140 000	.1140		
143 900	.....	....	Maximum resistance after the rest.
.....	.....	....	Sudden slip, load and reading now.
116 000	.1220	....	
127 000	.1257		
125 000	1260	....	Rested about 3 minutes.
136 500	.1275		
140 000	.....	....	Sudden slip.
122 000	.1338	....	After slip.
128 000	.2650	....	Movement continues.

The hoop kept in motion, the resistance varying from 128 000 to 138 000 pounds, with unsteady movement as before. A final sudden slip of the hoop reduced the load to 113 000 pounds, the total movement being .4970 inch when the test was discontinued. Time, 12:50 P.M.

Contact surfaces in sight were slightly rusty, which it is thought took place after the surfaces were exposed to the air.

After a rest under zero load of 25 hours 45 minutes, the loading was renewed.

113 000	.4970		
145 400	.....	....	Maximum resistance after above rest.
104 200	.5074	....	After sudden slip.
142 800	.52	Sec.	
133 000	.53	38	
136 000	.54	34	
129 000	.55	19	
141 000	.56	19	
136 000	.575	28	
137 000	.588 / .59	24	
137 000	.60	22	

FRICTIONAL RESISTANCE BETWEEN TUBE AND 3-INCH HOOP.

Details.—Continued.

Applied Loads.	Movement	Time.	Remarks.
Pounds.	Inches.	Sec.	
137 000	.612	22	
135 000	.625	19	
.....	.6375	23	
136 500	.64 }	24	
136 800	.65 }		
134 000	.662	18	
136 500	.675	20	
129 800	.684	15	
136 800	.698	19	
122 000	.7045	10	
136 400	.7165	18	
127 000	.725	13	
135 500	.7375	15	
128 000	.746	12	
128 900	.7545	12	
130 000	.764	13	
128 200	.775	11	
133 500	.786	18	
128 000	.794	11	
128 000	.804	14	
128 800	.814	11	
128 000	.8225	13	
128 400	.832	13	
128 100	.842	11	
135 000	.856	18	
129 000	.866	13	
128 000	.875	13	
128 500	.886	14	
128 200	.896	13	
127 000	.905	13	
129 000	.916	14	
135 200	.931	19	
128 000	.941	15	
127 000	.951	13	
128 200	.961	13	
127 100	.972	14	
127 100	.983	15	
127 400	.994	13	
127 200	1.00	19	
98 000	1.00	....	Rested 15 minutes.
125 000	.....	....	Maximum resistance after above rest.
117 000	1.10		
115 000	1.20	48	
113 000	1.30	52	
109 000	1.40	51	Number of Throbs between Readings.
105 000	1.50	52	
101 500	1.60	54	
97 500	1.70	47	11
91 000	1.80	48	12
84 000	1.90	50	13

Frictional Resistance between Tube and 3-inch Hoop.

Details.—Continued.

Applied Loads.	Movement	Time.	Number of Throbs between Readings.	Remarks.
Pounds.	Inches.	Sec.		
75 000	2.00	47	14	
68 000	2.10	48	14	
63 800	2.20	44	16	
57 000	2.30	44	16	
52 500	2.40	42	17	
47 500	2.50	42	22	
42 000	2.60	41		
39 900	2.70	34		
37 400	2.80	73		
31 000	2.90	73		

Frictional surface of the tube well polished, but retains marks of the turning tool.

Corresponding surface of the hoop shows no material change in its appearance resulting from the test.

Frictional Resistance between Tube and 4-inch Hoop.

Details.

Applied Loads.	Movement	Time.	Remarks.
Pounds.	Inches.		
50 000	0	....	Initial load.
100 000	.0024	....	Micrometer readings taken from holder to holder.
150 000	.0048		
200 000	.0068		
220 000	.0079		
240 000	.0089		
260 000	.0096		
280 000	.0102		
300 000	.0109		
320 000	.0118		
340 000	.0127		
350 000	.0132		
360 000	.0138		
370 000	.0143		
380 000	.0146		
390 000	.0149		
400 000	.0154		

FRICTIONAL RESISTANCE BETWEEN TUBE AND 4-INCH HOOP.

Details.—Continued.

APPLIED LOADS.	MOVEMENT	TIME.	REMARKS.
Pounds.	Inches.		
404 100	.....	....	Sudden slip. Maximum frictional resistance.
129 700	.0848	....	Load and reading after slip.
211 000	.0930	....	Continues the motion.
173 300	.2581	....	Rested 10 minutes.
187 800	.....	....	Maximum resistance after above rest. Motion caused without sudden slip.
193 800	.39		
202 000	.40	Sec.	
191 700	.41	65	
192 000	.42	27	
191 800	.43	32	
196 200	.44	31	
162 900	.45	24	
193 800	.46	23	
195 500	.47	25	
182 000	.48	..	
189 000	.49	..	
186 000	.50	7	
187 200	.51	9	
188 200	.52	9	
185 500	.53	9	
188 100	.54	9	
188 000	.55	9	
187 800	.56	8	
189 100	.57	10	
187 800	.58	9	
190 400	.59	10	
189 200	.60	8	
189 700	.61	9	
190 300	.62	8	
188 800	.63	9	
190 600	.64	10	
190 200	.65	10	
190 900	.66	10	
191 200	.67	8	
190 400	.68	9	
191 400	.69	10	
190 600	.70	9	
191 600	.71	9	
189 800	.72	9	
184 000	.73	8	Sudden slip.
188 000	.74	10	
184 000	.75	8	" "
190 400	.76	9	
183 000	.77	8	" "
188 000	.78	10	" "
189 000	.79	11	" "
180 000	.80	8	" "
187 000	.81	11	" "
189 000	.82	8	" "

FRICTIONAL RESISTANCE BETWEEN TUBE AND 4-INCH HOOP.

Details.—Continued.

Applied Loads.	Movement	Time.	Remarks.
Pounds.	Inches.	Sec.	
188 000	.83	9	
188 500	.84	11	
188 000	.85	6	
188 900	.86	13	
188 000	.87	6	
189 000	.88	12	
180 000	.89	9	Sudden slip.
178 000	.90	5	" "
179 000	.91	15	" "
.....	.92	6	
183 000	.93	11	
.....	.94	11	" "
176 000	.95	5	
189 800	.96	14	
182 900	.98	19	
173 900	1.00	..	Test discontinued. Time, 12:11 P.M.

Friction surfaces slightly rusty, occuring after exposure to the air. A few drops of water observed at the joint of the hoop and tube after the discontinuance of the test.

Test resumed after a rest of 26 hours 35 minutes under zero load.

100 000	1.00		
182 900	1.0060		
190 000	1.0085		
198 800	.....	....	Sudden slip.
145 000	1.0234	....	Load and reading after slip.
221 000	.....	....	Sudden slip. Maximum resistance after resting.
171 000	1.0817		
182 000	.....	....	Continues the movement.
186 000	1.10		
202 000	1.1375	Sec.	
178 000	1.145	49	
208 000	1.17	34	
188 000	1.1865	34	
183 000	1.19	25	
189 000	1.205	13	
182 000	1.218	26	
179 000	1 220	18	
193 000	1.238	19	
175 000	1.24	18	
185 000	1.255	14	
176 000	1.267	24	
179 000	1.27	13	
182 000	1.2816	11	
174 800	1.293	21	
178 000	1.307	20	
172 000	1 31	12	
172 800	1.319	7	

FRICTIONAL RESISTANCE BETWEEN TUBE AND 4-INCH HOOP.

Details.—Continued.

Applied Loads.	Movement	Time.	Remarks.
Pounds.	Inches.	Sec.	
170 000	1.332	18	
172 000	1.344	19	
174 800	1.357	18	
166 000	1.36	11	
171 000	1.369	7	
173 800	1.382	20	
169 800	1.393	17	
173 000	1.407	19	
164 000	1.41	11	
174 000	1.425	13	
165 000	1.433	18	
166 000	1.444	12	
174 000	1.4605	24	
163 000	1.47	18	
168 500	1.461	11	
170 000	1.477	23	
168 000	1.493	23	
162 000	1.503	15	
163 500	1.5135	14	
163 000	1.525	13	
164 500	1.5375	20	
158 000	1.54	9	
161 000	1.549	7	
163 000	1.561	14	
161 000	1.572	16	
161 500	1.585	16	
159 500	1.5955	15	
161 000	1.6080	16	
158 000	1.619	17	
159 800	1.6315	13	
161 500	1.649	22	
160 500	1.6645	20	
148 000	1.672	10	
159 500	1.689	21	
158 500	1.7045	19	
140 000	1.7115	11	
143 000	1.7190	7	
141 000	1.728	10	
148 000	1.736	9	
153 000	1.747	23	
144 000	1.753	18	
151 000	1.762	22	
149 500	1.77	23	
159 500	1.785	34	
139 000	1.79	17	
149 000	1.799	23	
148 000	1.808	20	
143 000	1.8145	18	
148 000	1.823	23	
148 000	1.832	21	

FRICTIONAL RESISTANCE BETWEEN TUBE AND 4-INCH HOOP.

Details.—Continued.

Applied Loads.	Movement	Time.	Remarks.	
Pounds.	Inches.	Sec.		
154 000	1.846	33		
139 000	1.8515	17		
145 000	1.86	20		
144 000	1.868	20		
142 000	1.875	19		
143 000	1.883	20		
152 000	1.8975	30		
134 000	1.9020	17		
143 500	1.91	20		
153 000	1.925	29		
123 000	1.998	..		
116 000	.....	..	Rested 15 minutes.	
139 500	.....	..	Sudden slip.	
145 000	.....	..	Maximum resistance after 15 minutes' rest.	
			Number of Throbs between Readings.	
128 000	2.12			
123 000	2.22	54		
114 000	2.30	46	12	
110 000	2.42	39	14	
105 000	2.50	44	15	
99 400	2.62	50	15	
93 800	2.72	49	16	
88 000	2.82	45	17	
83 500	2.92	45	18	
78 500	3.02	44	18	
74 300	3.12	48	19	
69 200	3.22	46	18	
64 600	3.42	87	34	
59 900	3.52	46	14	
54 500	3.62	44	13	
51 500	3.72	43	15	
51 800	3.82	42	11	
46 000	3.92	58	12	

After a movement of the hoop of 1.10 inches there was a succession of sudden slips, continuing through the remainder of the test.

Frictional surface of the tube well polished in a higher degree than the surface of the tube with the 3-inch hoop. The remaining tool marks also were deeper.

No material change produced on the corresponding surface of the hoop.

F. H. PARKER,
Major Ordnance Department, U. S. A.,
Commanding.

American Society of Civil Engineers.

PROCEEDINGS.

Vol. XII.—April, 1886.

MINUTES OF MEETINGS.

(Abstract of such as may be of general interest to members.)

OF THE SOCIETY.

April 7th, 1886.—The Society met at 20 o'clock, J. James R. Croes, Treasurer Am. Soc. C. E., in the chair. The following candidates were declared elected as Members: Howard Nixon Elmer, St. Paul, Minn.; John Butler Johnson, St. Louis, Mo.; Charles Ward Raymond (elected Junior November 7, 1877), Chicago, Ill.; William Burroughs Ruggles, Cincinnati, O.; George Edward Thackray (elected Junior September 6, 1882), Pittsburgh, Pa.; Ignacio Maria de Varona, Brooklyn, N. Y. As Associates: Samuel Stockton Bogart, New York, N. Y.; James Jackson Dana, New York, N. Y.; Henry Ayling Phillips, Worcester, Mass.; Frederick Stafford Young, Troy, N. Y. As Juniors: John Quincy Barlow, Tacoma, Wash. Ter.; John Joseph Donovan, North Yakima, Wash. Ter.; Stancliff Bazen Downes, New York, N. Y.; George Alfred Ricker, Buffalo, N. Y.; William Tuttle Shepard, New Haven, Ct.; Walter Obadiah Titus, Eagle Pass, Texas; Edward Ernest Russell Tratman, New York, N. Y.

The ballot on the following proposed amendment to the By-Laws was canvassed with this result: In the affirmative, 115 votes; in the negative, none.

The amendment is as follows:

By-Laws, Section 24, Clause 2d, final paragraph. Amend by substituting the following:

"When two or more persons have the highest and an equal number of votes at any election for officers, the Society shall elect the officer from among those having the highest and equal number of votes."

The amended clause will then read as follows:

2d. If it should appear that for any office a majority of the votes cast was not for one person, the meeting shall proceed to vote by ballot in the usual way for such officer, the choice of candidates being limited to the two persons not elected for whom the greatest number of votes had been previously cast for such office. When two or more persons have the highest and an equal number of votes at any election for officers, the Society shall elect the officer from among those having the highest and equal number of votes.

This amendment having been proposed in writing and seconded at the regular meeting of February 3d, 1886, submitted to vote of the Members by letter-ballot, and two-thirds of all the votes cast being in favor thereof, was declared duly adopted.

The paper by Joseph M. Wilson, M. Am. Soc. C. E., "On Specifications for Strength of Iron Bridges," was discussed by Messrs. Joseph M. Wilson and Theodore Cooper.

Mr. T. C. McCollom, M. Am. Soc. C. E., explained an apparatus made for the purpose of determining in 24 hours whether a cement is sound and safe to use, in connection with other tests. This apparatus has been presented to the Society by Mr. Henry Faija, of London.

April 21st, 1886.—The Society met at 20 o'clock, Mr. F. Collingwood, M. Am. Soc. C. E., in the chair.

A sketch by R. L. Harris, M. Am. Soc. C. E.. with drawings and memoranda of the ferry steamer Solana, by Arthur Brown, Superintendent Bridges and Buildings Central Pacific Railway, was read and discussed by Messrs. Emery, Dorsey, Striedinger, Macdonald, Collingwood and R. L. Harris.

The paper previously presented by Albon P. Man, Jr., M. Am. Soc. C. E., "Suggestions as to Flattening Ends of Railroad Curves," was discussed by Mr. A. M. Wellington.

OF THE BOARD OF DIRECTION.

March 31st, 1886.—Applications were considered, appropriations were made, financial business was transacted.

April 28th, 1886.—Applications were considered, financial business transacted.

ADDITIONS TO

LIBRARY AND MUSEUM.

From S. Thayer Abert, Washington, D. C.:

Annual Report upon the Improvement of certain Rivers and Harbors in Maryland, Virginia and North Carolina.

From American Academy Arts and Sciences, Boston:

Proceedings May, 1885, to October, 1885. New series. Vol. XIII, Part I.

From Admiral Daniel Ammen, U. S. N., Washington, D. C.:

The Certainty of the Nicaragua Canal contrasted with the Uncertainties of the Eads' Ship Railway.

From American Institute of Mining Engineers. Dr. R. W. Raymond, Secretary, New York City:

The Classification and Composition of Pennsylvania Anthracites. Chas. A. Ashburner.
Note on a Deposit of Fire Sand in Clinton County, N. Y. Alfred F. Brainerd.
The Sampling of Cast-Iron Borings. Porter W. Shimer.
Note on the Apatite Region of Canada. T. Sterry Hunt.
The Specific Gravity of Low Carbon Steel. George S. Miller.
The Nova Scotia Gold Mines. E. Gilpin.
The Process used at the Comstock for Refining Coppery Bullion produced by Amalgamating Tailings. A. D. Hodges, Jr.
Proceedings of the Forty-fourth Annual Meeting, Pittsburgh, February, 1885.
The Mineral Resources of the Hudson's Bay Territories. Robert Bell.
Professional Ethics. J. C. Bayles.
Recent Failures of Steel Boiler Plates. Wm. Kent.
A Chilled Blast Furnace Hearth. James Gayley.
Peculiar Phenomena in the Heating of Open Hearth and Bessemer Steel. William Garrett.
Mitis-Castings from Wrought-Iron or Steel. Peter Ostberg.
Notes on the Construction of Cast-Iron. C. B. Dudley and F. N. Pease.
Proposed Apparatus for Determining the Heating Powers of Different Fuels. Wm. Kent.
Note on the Determination of Small Quantities of Titanium in Irons and Steels. Horace L. Wells.
A New Method of Laying Submarine Tunnels and Tubes. Richard P. Rothwell.
The Specific Gravity of Low Carbon Steel. George S. Miller.
Note on a Cupel Machine. Prof. Charles E. Wait.
The Geology of the Pittsburgh Coal Region. J. P. Lesley.
Note on the Use of Gasoline-Gas in a Chemical Laboratory. Prof. Charles E. Wait.
Note on the Reduction of Ferric Solutions by the Use of Amalgamated Zinc and Platinum Foil. Alfred L. Beebe.
The Mining Compass and Trigonometer. Erich G. Gaertner.
Iron Ore Deposits of Southern Utah. W. P. Blake.
The Heine Safety Boiler. E. D. Meier.
The Manufacture of Fire-Brick at Mount Savage, Maryland. Robert Anderson Cook.
Biographical Notice of Oswald J. Heinrich. R. W. Raymond.
Geology of the Low Moor, Virginia, Iron Ores. Benj. Smith Lyman.
Pittsburgh and Vicinity—A Brief Record of Seven Years' Progress William P. Shinn.

From William S. Auchincloss, Philadelphia, Penn.:

Die practische Anwendung der Schieber-und Coulissensteurungen.

From James Barrowman, Secretary, Mining Institute of Scotland, Hamilton:

Transactions of the Mining Institute of Scotland. Vol. VII. Part 8.

From Gen. S. V. Benét, Chief of Ordnance, Washington, D. C.:

Annual Report of the Chief of Ordnance to the Secretary of War for the fiscal year ended June 30, 1885.

From H. Bissell, Salem, Mass.:

Merchandise Tariff of the Boston and Maine Railroad Leased Lines and Branches, adopted by the Directors January 21, 1885. To take effect February 1, 1885.

From Wm. H. Brown, Philadelphia, Penn.:

Record of Transportation Lines owned and operated by and associated in interest with the Pennsylvania Railroad, for the year ending December 31, 1885.

From C. H. Bunce, Hartford, Conn.:

Fourteenth Annual Report of the Board of Street Commissioners of the City of Hartford, for the year ending December 31, 1885.

From Bureau of Education, Washington, D. C.:

Report of the Commissioner of Education for the year 1883–84.
Circulars of information of the Bureau of Education, Nos. 3 and 4, 1885.

From Bureau of Navigation, Navy Department, Washington, D. C.:

Pilot Chart of the North Atlantic Ocean for the month of March and April, 1886.

From Bureau of Statistics, Washington, D. C.:

Statistical Abstract of the United States for 1885. Seventh and Eighth numbers.

From California Academy of Science, San Francisco, Cal.:

Bulletin of the California Academy of Science. No. 4. January, 1886.

From Thomas C. Chamberlain, Washington, D. C.:
The Requisite and Qualifying Condition of Artesian Wells.

From George H. Cook, New Brunswick, N. J.:
Annual Report of the State Geologist for the year 1885.
Atlas sheets Nos. 1, 9, 13 and 17 of the Geological Survey of New Jersey.

From Elmer L. Corthell, New York City:
An Exposition of the Errors and Fallacies in Rear-Admiral Ammen's Pamphlet, April, 1886.
Statement of Mr. Elmer L. Corthell before the Sub-Committee of the Committee on Commerce of the House of Representatives, in reference to the Commercial and other Advantages of the Ship Railway at the Isthmus of Tehuantepec in Mexico, February 5, 1886.

From Martin Coryell, Lambertville, N. J.:
Ninth Annual Report of the Directors of the Lambertville Water Company, March 11, 1886.

From William Cowles, New York City:
Improvement in Ferry Boats.

From Dawson Brothers, Publishers, Montreal, Canada:
The Manufacture, Consumption and Production of Iron, Steel and Coal in the Dominion of Canada.

From Frank C. Doran, Richmond, Ind.:
Five Photographs of the Three-hinged Wrought-Iron Arch Bridge, at Richmond, Indiana.

From Edward Bates Dorsey, London, England:
Three sample maps, Ordnance Survey of portions of England
Annual Statistical Report of the Secretary to the Members of the British Iron Trade Association on the Home and Foreign Iron and Steel Industries in 1884.
Whitaker's Almanack for 1886.
Fifty-sixth to Fifty-ninth Annual Reports of the President and Directors of the Baltimore and Ohio Railroad Co., for the year ended 30th September, 1882 to 1885.
A paper read before the Chesterfield and Derbyshire Institute of Engineers on Brunton's Heading Machine. William Johnson.
Report of Mr. Joseph Parry, C. E., on the Present Drought and on Possible Savings in the Consumption of Water, stated 13th July, 1885, City of Liverpool, Eng.
Report of Mr. George F. Deacon, C. E., as to the Vyrnwy Masonry Dam, City of Liverpool, England.
Various Time-tables of Railroads throughout England.

From Henry Drisler, Secretary Astor Library, New York City:
Thirty-seventh Annual Report of the Trustees of the Astor Library, for the year 1885.

From Pat Doyle, Black Town, Madras, India:
The Indian Coal Mines.
The first number of the *Indian Engineer*, Calcutta.
Coal Mining by Blasting in the Bengal Coal Field.

From James B. Eads, New York City:
Discussion on the paper of E. L. Corthell on the South Pass Jetties.

From Engineers' Society of Western Pennsylvania. S. M. Wickersham, Secretary, Pittsburgh:
Long Distance Transportation of Natural Gas.

From George E. Evans, Lowell, Mass.:
Thirteenth Annual Report of the Lowell Water Board. January 12, 1886.

From Avv. Cav. Maggiorino Ferraris, Segretario della Commissione d'inchiesta per la Revisione della Tariffa Doganale, Rome, Italy:
Atti della Commissione d'inchiesta per la Revisione della Tariffa Doganale. I Parte, Agraria.

From P. J. Flynn, East Oakland, Cal.
Kutter's Formula.

From Franklin Institute, Philadelphia, Penn.:
Reports of the Examiners of Section XI. Steam Engines.
Report of the Examiners of Section XXII. Supplementary Report on Meteorological and other Registers.
Report of Examiners of Section XXIX: "Educational Apparatus," with which is incorporated Section XIII: "Apparatus for High Electro-Motive Force."

From George H. Frost, New York City:
New Ordnance Material. William H. Bixby.

From E. A. Fuertes, Ithaca, N. Y.:
Catalogue of Engineers Graduated from Cornell University, Ithaca, N. Y., 1869–85.

From G. K. Gilbert:
Studien über die Gestaltung der Sandküsten und der Anlage von Seehäfen im Sandgebiet, von H. Keller.

From B. M. Harrod, New Orleans, La.:
Caving Banks on the Mississippi River. B. M. Harrod, C. E.

From Albert B. Hill, New Haven, Conn.:
Annual Report of the Department of the Board of Public Works, City of New Haven, Conn., for the year 1885.

From Ingersoll Rock Drill Co., New York City:
Views, Description and Progress of Work on the New Croton Aqueduct Tunnel, New York City, March, 1886.

From Institution of Civil Engineers, James Forrest, Secretary, London:
Proceedings, Vol. LXXXIII., 1885–86, Pt I.
On Construction in Earthquake Countries. John Milne. With an abstract of the discussion upon the paper.
On the Theory of the Steam Engine Indicator and the Errors in Indicator Diagrams. Osborne Reynolds.
Experiments on the Steam Engine Indicator. Arthur William Brightmore. With an abstract of the discussion upon the papers.
High-Speed Motors. John Imray.
Continuous Current Dynamo-Electric Machines and their Engines. Gisbert Kapp. With an abstract of the discussion upon the papers.

From Institution of Mechanical Engineers, Walter R. Brown, Secretary, London:

General Index to Proceedings, 1874–84.

From Improvement Association, Passaic, N. J.:

Passaic City, New Jersey, and its Advantages as a Place of Residence and as a Manufacturing Center.

From Iron and Steel Institute, J. S. Jeans, Secretary, London:

The Journal of the Iron and Steel Institute, No. 2, 1885.

From William Jackson, Boston:

Nineteenth Annual Report of the City Engineers of Boston, Mass., for the year 1885.

From Wm A. Jefferis, New York City:

Atlantic City as a Winter Resort.

From J. Francis Le Baron, Jacksonville, Fla.:

A Description of the History, Industries, Churches, Schools, Hotels, Hospitals and other Institutions, etc., of Jacksonville, Florida. By James Esgate.

Peninsular and Sub-Peninsular Air and Climate. W. C. Van Bibler, M. D.

A Hand-book of Important and Reliable Information for the use of the Tourist, Settler and Inventor in Florida. John P. Varnum.

From Liverpool Engineering Society, Thomas L. Miller, Secretary, Liverpool England:

Annual Report of the Liverpool Engineering Society for 1885.

From Major G. J. Lydecker, Engineer-Commissioner, Washington, D. C.:

Annual Report of the Operations of the Engineer Department of the District of Columbia, for the year ending June 30, 1885.

From R. K. Martin, Baltimore, Md.:

Annual Report of the Water Department of the City of Baltimore, Md., for the fiscal year ending December 31, 1885.

From Theodore H. McKenzie, Southington, Conn.:

Report of the Secretary and Engineer of the Southington Water Company on the Construction of the Water-works, Southington, Conn., December, 1885.

From the Mining Institute of Scotland, James Barrowman, Secretary, Hamilton:

Report relative to the Mining Exhibition held in Glasgow under the auspices of the Mining Institute of Scotland, September, 1885.

From Gen John Newton, Chief of Engineers U. S. A., Washington, D. C.:

Report of a Survey and Examination of Pascagoula River, Mississippi.

Report of an examination of Waeissa River, Florida.

Report from the Chief of Engineers in relation to Senate Bill 753, for the Sale of Fort Brady, Michigan.

Reports of Examination and Survey with a view of connecting Saugatuck River with Long Island Sound.

Report of a Survey of Saco River, Maine.

Report asking an Appropriation for Increasing the Water Supply of Washington, D.C.

Report of a Survey and of a Preliminary Examination of Muskingum River, Ohio.

Report of an Examination and Survey by Capt. H. S. Taber, Corps of Engineers, of Arkansas River, from Fort Gibson to Wichita, Kansas.

Report Recommending Legislation to Enforce Regulations concerning the Passage of Vessels through the South Pass, Mississippi River.

Tables of Geographic Positions, Azimuths, and Distances, etc.

In regard to the Improvement of Santee River, South Carolina.

In regard to Damage by Storms to Sea Wall in Boston Harbor.

A draft of a bill to Regulate the Use of Public Parks in the District of Columbia, and recommending its passage.

Report of additional surveys by Maj. Thomas H. Handbury, of routes for Hennepin Canal.

Report relative to the Government Pier on Delaware Bay.

Reports and maps showing encroachments of the Missouri River upon the Military Reservation at Fort Leavenworth, Kan.

Report in response to a resolution relative to the proposed purchase of the Franchise of the Green and Barren River Navigation Company by the United States.

Statement showing rank, duties, and addresses of the Officers of the Corps of Engineers, April 1, 1886.

Report upon the Improvement of the Entrance to Galveston Harbor.

Report recommending that Improvements be made in the Lockage of Saint Mary's Falls Canal.

From New York State Board of Health, Albany:

Bulletin of the State Board of Health for January and February, 1886.

From E. P. North, New York City:

One photograph of the Grand Central Depot, New York, Incoming Trains Depot.

From W. Osborne, Pillintzer Strasse, Dresden:

An Address to the Public in regard to the new 24-hour Clock.

From Park Commissioners, Boston:

Notes on the plan of Franklin Park, Boston, Mass., and relative matters.

From Ralph W. Pope, Secretary Am. Inst. Electrical Engineers, New York City:

Rules of the American Institute of Electrical Engineers, amended December 8th, 1885.

From Thomas Russell, Chairman Board of Railroad Commissioners, Boston:

Seventeenth Annual Report of the Board of Railroad Commissioners of Massachusetts for the year 1885.

From Collingwood Schreiber, Ottawa, Canada:

Annual Report of the Minister of Railways and Canals for the fiscal year, from 1st July, 1884, to 30th June, 1885, on the works under his control.

From Charles P. Shaw, New York City:

Argument of Robert Sewell, Engr., on behalf of the New York Cable Railway Co., before the Mayor of New York, 9th March, 1886.

From T. Guilford Smith, Buffalo, N.Y.:

Annual Report of the City Engineer, Buffalo, N. Y., for the year 1885.

Report of the Receivers of the P. and R. R. Co., and the P. and R. Coal and Iron Co., of the operations for the year ending November 30th, 1885.

From D. McN. Stauffer, New York City:

Proceedings of the Michigan Engineering Society at its Sixth Annual Convention, held at Lansing, February 17th, 18th, 19th and 20th, 1885.

On Tidal Theory and Tidal Predictions. E. A. Gieseler.

Report of the Governor of Washington Territory for the year 1884.

Report of the Trustees of the Sanitary Improvement Bonds of the City of Jacksonville, Fla., July 1st, 1884, to July 1st, 1885.

Speech of William L. Scott on the subject of the Coinage of the Standard Silver Dollar.

Topographical Models: their Construction and Uses. A. E. Lehman.

First Annual Report of the City Engineer of the City of Des Moines, for the year 1885.

River Transportatioo and the Muscle Shoals Canal. Major W. R. King.

Report of the Railroad Commissioners of the State of Maine for the year 1885.

The Cowles Electric Furnace and the Productions of Aluminium and its Alloys. Alfred H. Cowles.

Annual Report upon the Improvement of Harbors and Rivers on the Southern Coast of Massachusetts, and in Rhode Island and Connecticut.

Obituary Number of the *South Pennsylvania Transit*, Vol. II, No. 1. November, 1885.

Statistics of Coal in Illinois for the year 1885.

Report, with Plans and Estimates, for the Sewerage and Drainage of Orange, N. J.

A Summary of the Third Annual Report of the Bureau of Statistics of Labor of the State of New York for the year ending January 21st, 1886.

Annual Report of the Board of Managers of the New York State Reformatory at Elmira for the year ending September 30th, 1885.

Report to the Board of Trustees upon the Drainage and Sewerage for the Town of Lake, Ill. October, 1885.

Second Annual Report of the Board of Water Commissioners to the City of Northampton, Mass., for the year ending November 30th, 1885.

Report of the Board of Public Works of the City of Grand Rapids, Mich., for the fiscal year ending April 30th, 1885.

First Report of the Water Department of the Town of Wellesley from the beginning of the works, April, 1884, to July 1st, 1885.

The Twentieth and Twenty-first Annual Reports of the Cambridge Water Board for the years 1884 and 1885.

Tenth Annual Report of the Water Commissioners of the City of Taunton, Mass. November 30th, 1885.

Fourteenth Annual Report of the Superintendent of Water-works, Bay City, Michigan, for the year 1885.

Tenth Annual Report of the Lawrence, Mass., Water Board for the year 1885.

Report of the Board of Water Commissioners of the City of Middletown, Conn., for the years 1884 and 1885.

Twelfth Annual Report of the Board of Water Commissioners of the City of Springfield, Mass., for the year 1885.

Annual Report of the City Engineer of the City of Cambridge, Mass., for the year ending November 30th, 1885.

Third Annual Report of the Board of Water Commissioners of the City of Madison, Wis., for the year ending October 1st, 1885.

Report of the Consulting Engineers on Examination of the Sewerage System of the City of Newport, R. I. November 27th, 1885.

First Annual Report of the Board of Public Works of the City of East Saginaw, Mich., for the fiscal year ending January 5th, 1886.

Eleventh Annual Report of the Water Commissioners of the City of Allentown, Penn., for year ending December 31st, 1885.

Annual Report of the Board of Water Commissioners of the City of Binghamton, State of New York, for the year ending December 31st, 1885.

Fourteenth Annual Report of the Public Water Board of the City of Lynn, Mass., for the year ending December 31st, 1885.

Fourth Annual Report of the Board of Water Commissioners of the City of St. Paul, Minn., December 1st, 1885.

Sixteenth Annual Report of the New Bedford Water Board of the City of New Bedford, Mass., December 31st, 1885.

Annual Reports of the Committee on Water, the Water Commissioners, the Water Registrar and the City Engineer of the City of Worcester, Mass., for the year ending November 30th, 1885.

Annual Reports of the Department of the Board of Public Work, City of New Haven, Conn., for the year 1885.

General Buell's Map of the Battle-field of Shiloh.

An Analysis of the Laws of Motion: their relation to bodies moving in resisting media, and to various modes of steamship propulsion. John Giles.

Annual Accounts and Statements, with Superintendent's and Auditor's Reports, of the Sewerage and Water Supply for the City of Saint John (East Side) and Town of Portland, N. B., for the year ending December 31st, 1884.

Bound Pamphlers on Canals and Railroads, etc.

Annual Report of the Chief Engineer of the Water Department of the City of Philadelphia for the year 1872.

The Practice of the Improvement of the Non-Tidal Rivers of the United States, with an Examination of the Results thereof, by Captain E. H. Ruffner, Corps of Engineers, U. S. A.

From Lucian A. Taylor, Worcester, Mass.:

Annual Reports of the Committee on Water, the Water Commissioner, the Water Registrar and the City Engineer of the City of Worcester, for the year ending November 30th, 1885.

Prom J. Nelson Tubbs, Rochester, N. Y.:

Proceedings to acquire Water Rights by the City of Rochester, N. Y. Vos. I and II.

From United States Naval Institute, Annapolis, Md:

Proceedings, Vol. XII, No. 1.

From United States Geological Survey, Washington, D. C.:

Fifth Annual Report of the United States Geological Survey, 1883–84.

27 maps U. S. Geological Survey.

From Edmund B. Weston, Providence, R. I.:
Annual Report of the Commissioner of Dams and Reservoirs made to his Excellency, Augustus O. Brown, Governor, January 1, 1885.
The Distribution of Rainfall in New England February 10th-14th, 1886, from Observations reported to the New England Meteorological Society. Wilson Upton.
Bulletin of the New England Meteorological Society for February, 1886.

From C. J. H. Woodbury, Boston Mass.:
An Address before the National Electric Light Association, Baltimore, Md., on the Relation of Electric Lighting to Insurance.
Second Report on Automatic Sprinklers.

From Stephen M. Wright, Secretary General Society of Mechanics and Tradesmen, New York City:
One Hundredth Annual Report of the General Society of Mechanics and Tradesmen of the City of New York, 1886.

From Charles G. Yale, Secretary Technical Society of the Pacific Coast, San Francisco, Cal.:
Transactions for October, November and December, 1885, and January and February, 1886.

From other sources:
Ransome's Concrete Construction.
Opinions of the Press on the Effect on City and State Credit.
Hand-book and Illustrated Catalogue of the Engineers' and Surveyors' Instruments made by Buff & Berger.
An Address delivered before the New York Academy of Sciences November 23d, 1885, by R. M. Caffall, on his Process for Water-proofing and Preserving Buildings, as recently applied to the Obelisk in Central Park.
Proposals, Contracts and Specifications for Furnishing Vitrified Salt - Glazed Clay Water-pipe for Little Falls, N. Y., Waterworks.
Pamphlet of the Carolina Oil and Creosote Company on the Manufacture of Carbonized and Wood-Creosoted Timber and Cross-Ties, and Wood-Creosote Oil.

LIST OF MEMBERS.

ADDITIONS.

MEMBERS.	Date of Election.
ELMER, HOWARD NIXON.....St. Paul, Minn.....	April 7, 1886.
RAYMOND, CHARLES WARD....(Elected Junior November 7, 1877) Care Sooysmith & Co., 52 Montauk Block, Chicago, Ill....	" " "
THACKRAY, GEORGE EDWARD...(Elected Junior September 6, 1882), Box 117, Sharpsburg, Pa.	" " "
VARONA, IGNACIO MARIA DE...223 East 31st street, New York City.....	" " "
ASSOCIATES.	
DANA, JAMES JACKSON.....140 Pearl street, New York City...	" " "
PHILLIPS, HENRY AYLING.....Division Superintendent Fitchburg R. R., Worcester, Mass....	" " "
JUNIORS.	
BARLOW, JOHN QUINCY.....Northern Pacific R. R., Ellensburg, Wash. Territory.....	" " "
DOWNES, STANCLIFF BAZEN...1071 Madison Avenue, New York City.....	" " "
RICKER, GEORGE ALFRED .....53 Twelfth street, Buffalo, N. Y...	" " "
SHEPARD, WILLIAM TUTTLE....18 City Hall, New Haven, Conn...	" " "
TRATMAN, EDWARD ERNEST RUSSELL.....170 Clinton street, Brooklyn, N. Y.	" " "

CHANGES AND CORRECTIONS.

MEMBERS.

Atwood, William H.....Astoria, Queens Co., N. Y.
Bell, Henry P.....Esquimault and Nanaimo R'y, Cowichan, British Columbia.
Brooks, Fred.....31 Milk street, Boston, Mass.
Clement, Frank H.....Civil Engineer and Contractor, Ardsley, N. Y.
Clarke, Eliot C.....15 Brimmer st., Boston, Mass.
Cunningham, David W.....Grandin, Cass Co., Dakota.
Endicott, Mordecai T.....Civil Engineer U. S. N., U. S. Navy Yard, Norfolk, Va.
Falconet, Eugene F.....Engineer Etna Iron Co., Nashville, Tenn.
Filley, Hiel H.....Chief Engineer Southern General Division Mexican National R'y, Mexico, Mexico.
Hemberle, Edward.....14 Douglas st., Karlsruhe, Baden, Germany.
Linville, Jacob H.....3924 Walnut st., West Philadelphia, Pa.
McCollom, Thomas C.....Civil Engineer U. S. N., League Island, Pa.
Orbison, Thomas W.....Appleton, Wis.
Parkhurst, Henry W.....Bristol, R. I.
Pegram, George H.....9 South st., New York City.
Pou, Arthur.....Chief Engineer Savannah, Dublin and Western Short Line R'y, Savannah, Ga.
Pratt, William A.....Weston, Lewis Co., West Va.
Prindle, Franklin C.....Civil Engineer U. S. N., East Orange, N. J.
Purdon, Charles D.....Paris and Great Northern R'y, Paris, Texas.
Safford, Edward S.....Arlington, Mass.
Sears, Alfred F.....Helena, Montana.
Staats, Robert P.....171 Broadway, New York City.
Walker, John S.....Box 45, Texarkana, Texas.
Wilder, Francis M.....Binghamton, N. Y.

JUNIORS.

Blanc, Frederick N.....14 West 23d st., New York City.
Booker, Bernard F.....Lock-Box 6, Keokuk, Iowa.
Breithaupt, William H.....4 Lockridge Hall, S.E. Corner Main and Fifth sts., Kansas City, Mo.
Carrère, J. Maxwell.....466 Henry st., Brooklyn, N. Y.
Fuller, William B.....4 Bunnell Block, Duluth, Minn.
Gay, Martin.....West New Brighton, Richmond Co., N. Y.
Goldmark, Henry.....32 Liberty st., Room 11, New York City.
Smith, Maxwell.....109 East 72d st., New York City.

DEATH.

Bailey, Thomas Norton.....Elected Member November 7th, 1883; died April 20th, 1886.

American Society of Civil Engineers.

PROCEEDINGS.

Vol XII.—May, 1886.

MINUTES OF MEETINGS.

(Abstract of such as may be of general interest to members.)

OF THE SOCIETY.

May 5th, 1886.—The Society met at 20 o'clock, Vice-President Thomas F. Rowland, in the chair; John Bogart, Secretary. The following candidates were elected as Members: Almon Byron Atwater, Detroit, Mich.; Frederick Eaton, Los Angeles, Cal.; Eugene Frederick Fuller, Paducah, Ky.; Albert Mather Smith, New York City; Charles Sooysmith, New York City; Augustine Washington Wright, Chicago, Ill. As Junior; John Jacob Hopper, New York City.

The election as Fellow of the Society of Amzi Lorenzo Barber, of Washington, D. C., was announced.

The death of Capt. Thomas Norton Bailey, M. Am. Soc. C. E., Corps of Engineers, U. S. A., on April 20th, 1886, was announced.

The report of the committee appointed to place before the General Railway Time Convention the information gathered by the Society in regard to Standard Time, was read, stating that the Time Convention had appointed a special committee on the subject. The report was accepted and the committee discharged.

The paper previously presented on "English and American Railroads Compared," by Edward Bates Dorsey, M. Am. Soc. C. E., was discussed by Messrs. G. Bouscaren, J. Henney, Jr., Edward Pritchard, M. Inst. C. E., R. L. Harris, and Dorsey.

Blue prints of two heavy locomotives now in use by the Southern Pacific Co., Pacific System were presented by Mr. A. J. Stevens, Master Mechanic, through R. L. Harris, M. Am Soc. C. E., and the thanks of the Society were tendered to Mr. Stevens for these drawings and the accompanying information.

May 19th, 1886.—The Society met at 20 o'clock, Vice-President Thomas F. Rowland, in the chair; John Bogart, Secretary.

The death of James D. Burr, M. Am. Soc. C. E., on May 7th, 1886, was announced.

The paper previously presented on "Errors in Railroad Levels," by H. V. Hinckley, M. Am. Soc. C. E., was discussed by L. L. Wheeler, M. Am. Soc. C. E.

A paper by Capt. O. E. Michaelis, M. Am. Soc. C. E., Corps of Ordnance, U. S. A., "A Note on the Cost of Concrete" was read.

MEMOIRS OF DECEASED MEMBERS.

THOMAS SYDENHAM HARDEE, M. Am. Soc. C. E.

Died May 20th, 1880.

Thomas Sydenham Hardee was born in Liberty County, Ga., in the year 1832. His father was a physician of that place. He was named after Thomas Sydenham, a celebrated English physician. He graduated from the University of Georgia at the age of eighteen and was then offered the choice of an education as a civil engineer or of a thorough training in Italy in music, as he had at a very early period developed remarkable musical tastes. He however preferred the technical education and became a student at West Point, taking a special course under the instruction of Prof. Mahan. After the completion of his studies he became engaged upon the location of the New Orleans and Great Northern Railroad, and was in active service upon that and other railroads for about ten years.

At the commencement of the war he entered the Confederate service as Captain of Engineers, and was upon the staff of his uncle, General W. J. Hardee, becoming afterwards Lieutenant-Colonel of Engineers in that service. He was actively engaged in engineering duties during the war, being for a part of the time also upon the staff of General Joseph E. Johnston, and won many commendations for gallantry, skill and coolness.

Afterwards he was special engineer and member of the Railroad Board of Inspection of the State of Mississippi. In 1870 he went to New Orleans and prepared for the State a very valuable map of Louisiana. In 1874 he became the City Surveyor of New Orleans, and gave careful attention to the problem of the drainage of that city, which was at that

time in a deplorable condition, the various districts of the city having separate systems for the disposal of their drainage. He recommended that, before any additional work should be undertaken, a thorough topographical survey of the city should be made and a general plan of drainage determined upon to be carried out through a series of years. He prepared and recommended a plan for this purpose which involved an expenditure of a very much less amount of money than would have been expended had the plans previously considered for this purpose been carried out. The financial condition of the city, however, was such, that it was deemed impossible at that time to carry out any proper plan of drainage. A plan of his for securing a better and more wholesome supply of water to the city was also given up on account of financial difficulties.

In 1876 he was elected Chief Engineer of the Louisiana Levee Company, and afterwards was made Assistant-Engineer of the State, and, on the resignation of Major B. M. Harrod, M. Am. Soc. C. E., he became Chief Engineer of the State of Louisiana. In this position he had charge of the construction of the levees of the State. He constructed the works of repair at the great break at Bonnet Carré, and also the break in the Sharp Levee opposite the City of New Orleans, where he exposed himself while suffering from illness and never recovered from the effects of that exposure.

Colonel Hardee was one of the most trusted engineers in the South. He added to a thorough technical education, very great industry and zeal in the practical works of his profession.

In 1861 Colonel Hardee married Miss Harriot Zacharie, and his widow and six sons survive him. He was elected a Member of the American Society of Civil Engineers April 4th, 1877.

LIST OF MEMBERS.

ADDITIONS.

MEMBERS.

		Date of Election
JOHNSON, JOHN BUTLER	Washington University, St. Louis, Mo.	April 7, 1886.
RUGGLES, WILLIAM BURROUGHS	Chief Engineer Ohio and Mississippi Ry., Cincinnati, Ohio	April 7, 1886.
SMITH, ALBERT MATHER	Consolidated Gas Co., Tenth ave. and 18th st., New York City	May 5, 1886.
SOOYSMITH, CHARLES	2 Nassau st., New York City,	May 5, 1886.

WRIGHT, AUGUSTINE WASHINGTON..185 Dearborn st. (Room 7), Chicago, Ill..... May 5, 1886.

ASSOCIATES.

BOGART, SAMUEL STOCKTON.....Superintendent Telegraphs and Signals, West Shore R. R., foot West 42d st., New York City ..... April 7, 1886.

YOUNG, FREDERICK STAFFORD .....350 Broadway, Troy, N. Y.. April 7, 1886.

JUNIORS.

DONOVAN, JOHN JOSEPH .....Northern Pacific R. R., Ellensburgh, Wash..... April 7, 1886.

TITUS, WALTON OBADIAH..... P. O. Box 109, Eagle Pass, Texas..... April 7, 1886.

FELLOW.

BARBER, AMZI LORENZO.....280 Broadway, New York City..... March 19, 1886.

CHANGES AND CORRECTIONS.

MEMBERS.

ATWOOD, WILLIAM H.....Chatham, Mass.

BAKER, WILLIAM H.....Fitchburg, Mass.

DRAKE, WILLIAM A.....Resident Engineer, Atchison, Topeka and Santa Fé R. R., Topeka, Kansas.

FANNING, JOHN T.....Chief Engineer St. Anthony's Falls Water Power Co., Union Depot, Minneapolis, Minn.

GATES, HORACE D.....2800 Pine st., San Francisco, Cal.

GOAD, CHARLES E.....102 St. Francis Xavier st., Montreal, Canada.

HENNING, CHARLES S.....Cherokee, Kansas.

HOFF, OLAF.....25 and 26 Tribune Building, Minneapolis, Minn.

MCGRATH, WALLACE.....Care Chief Engineer Atchison, Topeka and Santa Fé R. R., Topeka, Kansas.

NEILSON, CHARLES.....General Superintendent Cincinnati, Hamilton and Dayton R. R., Cincinnati, Ohio.

SEARS, CLINTON B.....Captain Corps of Engineers, U. S. A., University Club, New York City.

THACKRAY, GEORGE E.....Box 789, New York City.

VAN BROCKLIN, MARTIN.....Care Messrs. R. Towns & Co., Sydney, Australia.

JUNIORS.

EMONTS, WILLIAM A. G.....(Care C. H. Kellogg), 24 Erie st., Buffalo, N. Y.

FRANCIS, GEORGE B. ..... Assistant Engineer New Jersey Junction R. R., 173 Bergen ave., Jersey City, N. J.
HASKINS, WILLIAM J. ..... 537 West 105th st., New York City.
SHEPARD, WILLIAM T. ..... (Care N. C. Ray, Assistant Engineer Union Pacific Ry.), Anaconda, Montana.

DEATH.

BURR, JAMES D. ..... Elected Member April 5, 1876; died May 7th, 1886.

CONTRIBUTIONS TO THE BUILDING FUND.

By a resolution of the Board of Direction, all contributions to the Building Fund are to be acknowledged, from time to time, by printing lists of the same in the monthly Proceedings of the Society, and in addition to this, the names of all those who may subscribe $100 or more are to be regularly enrolled and published in future lists of the Society under the head of Subscribers to the Building Fund, and they will be entitled to receive one copy of the monthly publications, comprising all papers and Transactions of the Society, regularly for life, for each $100 subscribed by them; such copies to be in addition to those which they may be already entitled to if they are Members or Fellows.

The following contribution is acknowledged in addition to those heretofore noted:

Frederic Graff $200.00

THE ROWLAND PRIZE.

CODE OF RULES FOR ITS AWARD.

Not more than one prize shall be awarded each year for papers presented during the year. The year shall terminate on the first day of August, and the award shall be announced at the annual meeting in January.

The prize shall consist of fifty dollars in cash.

The award shall be made by a committee consisting of the Secretary and two Members of the Society, to be appointed by the Board of Direction.

The prize shall be awarded to such paper as the committee deem most worthy of such recognition, the preference being given to papers describing in detail accomplished works of construction, their cost and manner of execution, and the errors in design and execution.

THE NORMAN MEDAL.

CODE OF RULES FOR ITS AWARD.

I.—Competition for the Norman Medal of the American Society of Civil Engineers shall be restricted to Members of the Society.

II.—There shall be one gold medal, and only one, struck for each and every fiscal year of the Society, and awarded as hereinafter provided. The dies therefor shall be with the Superintendent of the United States Mint at Philadelphia, in trust exclusively for the above purpose. Such medal shall be of a cost equal to the annual interest received upon $1 000 of the Consolidated Stock of the City of New York, Certificate No. 179, of the additional new Croton Aqueduct Stock of the City of New York, authorized by an Act of the Legislature of the State of New York, Chap. 230, passed April 15th, 1870, dated November 17th, 1873, now held in trust by the Treasurer of this Society, and so held solely for this purpose, and shall be executed upon his order.

III.—All original papers presented to the Society by Members of any class, during the year for which the medal is awarded, shall be open to the award, provided that such papers shall not have been previously contributed in whole or in part to any other association, nor have appeared in print prior to their publication by the Society, nor have been presented to the Society in any previous year.

IV.—The Board of Censors to award the medal shall consist of three Members of the Society, to be designated by the Board of Direction. The Secretary of the Society shall act as Secretary to the Board of Censors.

V.—The medal shall be awarded to such paper as the said Board shall judge to be worthy of special commendation for its merits as a contribution to engineering science, not merely relatively as compared with others presented during the same year, but as exhibiting the science, talent or industry displayed in the consideration of the subject treated of, and for the good which may be expected to result from the discussion and the inquiry.

VI.—In case no paper presented during the year shall be deemed of sufficient value to receive an award, the amount of the interest of the fund for that year shall be expended by the Board of Direction in the purchase of books, to be offered as a premium for the second best paper in the next year in which more than one paper of sufficient value may be presented.

VII.—The medal year shall terminate on the first day of August, and the award shall be announced at the annual meeting.

VIII.—The Treasurer of this Society shall cause the medal to be prepared and delivered to, or deposited to the order of, the successful competitor, within two months after the annual meeting at which the same shall have been awarded.

American Society of Civil Engineers.

PROCEEDINGS.

Vol. XII.—June, 1886.

MINUTES OF MEETINGS.

(Abstract of such as may be of general interest to members.)

OF THE SOCIETY.

June 2d, 1886.—The Society met at 20 o'clock, Past President George S. Greene in the chair; John Bogart, Secretary. The following candidates were declared elected. As Members: William Algernon Brackenridge, Brooklyn, N. Y.; Robert Gillham, Kansas City, Mo.; Arthur Henshaw Howland, Boston, Mass.; Richard Leveridge Hoxie, Montgomery, Ala.; Herbert Sherman Huson, North Yakima, Wash. Ter.; Charles Edward Jackson, New York City; William Henry Lawton, Jr., Newport, R. I.; Samuel Bingham McKee, Montreal, Canada; Charles Henry Sawyer, Stanberry, Mo.; John Stewart Schaeffer, Newark, N. J.; Addison Moffat Scott, Charleston, West Va.; John Findley Wallace, Keithsburg, Ill. As Associate: Calvin Milton Woodward, St. Louis, Mo. As Juniors: Samuel Eben Barney, Jr., New Haven, Conn; Charles Pierre Bonnett, Elizabeth, N. J.; Nathaniel Oliver Goldsmith, Glendale, Ohio; Charles Malon Mills, New York City; Henry Bowman Seaman, Brooklyn, N. Y.

The election as Fellow of the Society of John Joseph Albright, of Buffalo, N. Y., was announced.

A paper by Palmer C. Ricketts, Assoc. Am. Soc. C. E., "Some Constants of Structural Steel," was read and discussed.

A model of an apparatus for climbing chimneys, for purposes of construction and repair, was exhibited by Mr. Arthur Westcott, of Liverpool, England.

LIST OF MEMBERS.

ADDITION.

FELLOW.		Date of Election.
ALBRIGHT, JOHN JOSEPH	Buffalo, N. Y.	April 20, 1886.

CHANGES AND CORRECTIONS.

MEMBERS.

BRINCKERHOFF, HENRY W. ..... 41 Jefferson avenue, Brooklyn, N. Y.

CHILDS, JAMES E. ..... General Manager New York, Ontario and Western R. R., 16 Exchange Place, New York City.

CRAVEN, HENRY S. ..... Civil Engineer, U. S. N., Kittery Point, Me.

DAVIS, CHARLES E. L. B. ..... Captain Corps of Engineers, U. S. A., P. O. Drawer 7, Milwaukee, Wis.

DOANE, WALTER A. ..... (Care Lewis Kingman, Asst. Chief Engineer Atchison, Topeka and Santa Fé R. R.), Topeka, Kan.

DRAKE, WILLIAM A. ..... Resident Engineer Atchison, Topeka and Santa Fé R. R., Topeka, Kansas.

FLAGG, J. FOSTER ..... Division Engineer New York Steam Co., 21 Cortlandt st., New York City.

GATES, CHRISTOPHER L. ..... Engineer Smith Bridge Co., Toledo, Ohio.

GRANT, WILLIAM H. ..... 209 West 55th st., New York City.

PARTRIDGE, JOHN A. ..... 627 F st., N. W., Washington, D. C.

WHEELER, LEVI L. ..... P. O. Box 1073, Jackson, Mich.

JUNIORS.

BENSEL, JOHN A. ..... 64 E. 79th st., New York City.

LUCAS, D. JONES ..... Port Jervis, N. Y.

American Society of Civil Engineers.

PROCEEDINGS.

Vol. XII.—July, 1886.

MINUTES OF MEETINGS.

(Abstract of such as may be of general interest to members.)

ANNUAL CONVENTION OF THE SOCIETY,

HELD AT DENVER, COLO., JULY 2D, 3D, 5TH AND 7TH, 1886.

FIRST SESSION.

FRIDAY, JULY 2D, AFTERNOON.—The Convention assembled in the hall of the Chamber of Commerce, and was called to order at 15:15 o'clock by Mr. JOHN BOGART, the Secretary of the Society, who said:

I have the honor of calling the Colorado Convention of 1886, of the American Society of Civil Engineers, to order, and I have the pleasure of introducing to the Society its President, Colonel HENRY FLAD.

President FLAD.—Gentlemen: Under the By-Laws of the Society, a Chairman selected from Members, not officers, is to preside over all but business meetings of the Convention. If the Local Committee is ready to make a nomination, we will be glad to hear from them.

Mr. GEORGE S. RICE, M. Am. Soc. C. E.—I nominate for Chairman, Mr. Robert B. Stanton, of Denver.

The nomination of Mr. Stanton was carried, and that gentleman took the chair.

Mr. ROBERT B. STANTON, M. Am. Soc. C. E.—Gentlemen: It is hardly necessary for me to say that I appreciate the honor you have conferred on me in appointing me to this position, being so young a Member of our Society, and I have only to say, that as we, Members of this Society in

Denver, are so few—only two—we doubly welcome you to our State. In accordance with the usual custom at conventions, Past Presidents of the Society are invited to occupy seats upon the platform.

The Secretary then made announcements in regard to the meetings. He also presented the following letter:

To the President and Members of the American Society of Civil Engineers now in Session at the Chamber of Commerce.

The Executive Committee in charge of the celebration of the Fourth of July, 1886, will be honored by your presence at this double anniversary—the One Hundred and Tenth Anniversary of the Independence of the United States, and the Tenth Anniversary of the founding of the State as a State. The parade will move at 4 o'clock P. M. sharp, Monday, July 5th. If the invitation is accepted, please advise the undersigned.

J. BROOK,
Secretary of the Executive Committee.

Prof. C. M. WOODWARD, Assoc. Am. Soc. C. E.—I move that the invitation be accepted.

The motion was carried.

The CHAIRMAN.—Are there any suggestions or motions to be made by any person present before we proceed to the reading of a paper. If not, perhaps you gentlemen who are visiting Colorado will appreciate what an interesting subject you have brought to Colorado people as an introductory to your Convention, when I announce a paper by Captain R. L. HOXIE, M. Am. Soc. C. E., on the subject of "Excessive Rainfalls." It hardly seems intended for Colorado. However, we shall be interested in the Secretary's reading of it.

The Secretary read the paper. It was discussed by Messrs. J. J. R. Croes, David E. McComb, Robert E. McMath, Robert B. Stanton, George S. Rice, Thomas C. Keefer, John F. Barnard, Eliot C. Clarke, F. Collingwood, Jacob Blickensderfer and Charles Latimer.

The Chairman then, in behalf of the Local Committee, presented to the Members a book prepared for their use and giving very full information as to the City of Denver and the State of Colorado. The book is handsomely illustrated.

Attention was called to the exhibition in the meeting room of a number of specimens of the native building stones of Colorado. Also of Portland cement manufactured at Denver.

SECOND SESSION.

JULY 2D, EVENING.—The Members of the Society and its guests assembled at the Tabor Grand Opera House at 20:30 o'clock.

The Chairman, Mr. ROBERT B. STANTON, M. Am. Soc. C. E., in opening the meeting, said:

Ladies and Gentlemen: We are assembled here this evening to welcome to our State and City the American Society of Civil Engineers, and

as a citizen of Colorado I take great pleasure in introducing to you His Excellency Governor EATON.

GOV. EATON.—Mr. Chairman, Ladies and Gentlemen: Never before in the history of Colorado have we been honored as we are to-night. Our distinguished visitors are the forerunners of progress, the corner-stone of modern civilization. To the American engineers, their skill, their energy and their science, are more due the grand strides that civilization is making in the last half century than to any other cause. You have annihilated space and bid defiance to time. With iron bands you have connected ocean to ocean. You cause palaces to fly on wheels for our comfort and our pleasure, and to-day the world is electrified by your thought. Over thirty years ago I was holding the rod and carrying the chain for one of your distinguished members, Mr. Jacob Blickensderfer. Owing to a lull in railroad building, I took Horace Greeley's advice, and started West to grow up with the country, never expecting to see Ohio's State Engineer again. A few years passed, and I found him leading the iron horse across the great American Desert, and over our pathless mountains.

Judging of the future by the past, we have a grand and glorious prospect before us. Our hope of the future is in you. Stand by your noble calling. In behalf of the people of the State I would welcome you. I trust your visit with us may be an oasis, the shadow of a great rock in a weary land, a green spot on memory's brightest page.

Mr. HENRY FLAD, President of the Society, responded as follows.—Your Excellency: I thank you most heartily on behalf of the American Society of Civil Engineers for the kind words of welcome you have spoken to us. We came to your city to hold our Annual Convention, because we wanted to see the great works of engineering art in which your State excels—your mountain railroads and your irrigation works. But this was not the only cause for our coming. We had a common, human interest in investigating the causes of a progress which may be called unprecedented in the history of the world, when it is considered that where a few decades ago there was nothing but a desert, to-day there is a flourishing city of seventy thousand inhabitants, enjoying all the material and intellectual benefits of civilization. And last, but not least, we wanted to make the personal acquaintance of the hardy race of men who wrought these changes, and were convinced that they would extend to us the hand of brotherhood as members of a profession whose object it is, if I may be allowed to make a new definition, to overcome and remove all obstacles in the way of the material progress of the human race with the least exertion of power. In this expectation we were not deceived. Your greeting assures us that we will be welcome here, and I can assure you that we will use the opportunity offered us so

kindly to make ourselves familiar with all your works of engineering, and to become acquainted with your people. I again thank you for this kind reception.

The Chairman, Mr. R. B. STANTON.—On behalf of the City of Denver, I have the pleasure of introducing to you Mr. THOMAS NICOLL, the acting Mayor.

Mr. NICOLL.—Ladies and Gentlemen, Mr. President and Members of the American Society of Civil Engineers: It is with pleasure that I welcome you to our city, welcome you as individuals and as an association. We are glad to have representative men come among us, and honor the City of the Plains with their deliberations, and especially is this true when the association is of such importance as your organization, whose Members have, in the drainage of our cities and in the construction of other great works, left monuments to their skill that will remain long after the designer's hand is still in death and his eyes closed to worldly responsibilities and cares. The advance of a people is probably most strikingly indicated by the character of their public works. Perhaps nowhere on the continent is this fact more decidedly evident than in Colorado. What miracles have been wrought here in scarcely a score of years through the science which you represent. We have no wonders in great buildings or massive granite works. We have no St. Louis Bridge, no Erie Canal; but our mountains have been surmounted by marvels of engineering that are famous the world over. Our plains have been transformed into gardens by the handiwork of the canal builder. The precious contents of our mines have been brought to the use of civilization through the best thoughts of the mining engineer, and the healthfulness of this region has been largely enhanced by sanitary science, and a very large share of the prosperity we enjoy to-day is the result of the study, care and skill of the members of your profession. The citizens of Denver feel honored by your choice of this city as a meeting place. In your brief respite from business responsibilities, and after your adjournment, remember that you are in the midst of a hospitable people, the proud owners of a delightful and wonderful city, and that I have, in obedience to a general call, extended, and do now extend, to the Members here assembled of the American Society of Civil Engineers, the hospitality, freedom and good-will of the City of Denver.

The Chairman, Mr. R. B. STANTON.—As you are aware, this is the American Society of Civil Engineers, and embraces all America. I have the honor to introduce to you our Vice-President, Mr. THOMAS C. KEEFER, of Ottawa, Canada.

Mr. THOMAS C. KEEFER, Vice-President Am. Soc. C. E.—Ladies and Gentlemen: I have great pleasure on behalf of our Society in

recognizing the very kind reception which you have prepared for us, and the very kind sentiments expressed by your Mayor. I am sure that on this, our visit to Colorado, we are as much surprised by the City of Denver as by your mountains. The solidity of the buildings in this city, the complete municipal equipment which it possesses, show that your citizens are as much in advance of our older corporations in the East as your mountains are higher than our hills. There is a great deal to attract us Eastern people in Colorado especially. It is the nearest point where we can get elevation and civilization combined. There are many higher mountains and many places of great interest, but they are very difficult to get at, and when you get there you cannot stay there. But Colorado is, by the wonderful energy of her people, made accessible in its mountains and in its most beautiful scenery, and her people have so developed their health resorts and natural springs, that undoubtedly it will become the Switzerland of America, and when you have further advanced in this mountain development, and have more railroads from the East, you will have, I think, as much tourist travel in this State in proportion to the whole Union as Switzerland has in Europe, and that is the most profitable business that Switzerland has.

We are also pleased in coming to Colorado, because not only have we mountains covered with snow and these high elevations, but we see your prairie dogs and your jack-rabbits, which we have not in the East, and we see the wonderful effects of irrigation. That is a new thing to Eastern people. We pass over what is called the American Desert and we find a city here, a sort of Palmyra in the wilderness, which astonishes every one who sees it, and at which every person in crossing the continent—in passing from the Atlantic to the Pacific—wishes to make a stop for the reasons which I have stated, the natural beauties of this wonderful State and City.

I have been warned that new comers should not indulge in much speaking, as it is apt to produce hoarseness, and therefore I will content myself with renewing my thanks to you, Mr. Mayor, and to the citizens of Denver for this very flattering reception. This is my first appearance on this or any other stage.

The Chairman, Mr. R. B. Stanton.—To a Denver audience our next speaker needs no introduction, but to the Members of the American Society of Civil Engineers I wish to say that to his kind suggestion you will owe a great deal of your enjoyment while in this city. I have the honor to introduce to you Mr. R. W. Woodbury, the President of the Chamber of Commerce.

Mr. R. W. Woodbury.—Mr. President, Ladies and Gentlemen: The ingenuity and experience of fifty centuries have built a pinnacle of knowledge that excites the admiration and wonder of the average man

who looks toward its summit and along the rugged steps that lead thereto, and it causes him to speculate in the realm of wildest imagination at the possible height that may be attained in the far distant future. Very few men reach the summit of that pinnacle and look down; but if there be any particular profession which is there represented by a greater percentage of its members than another, I believe it to be that of the civil engineer. The very name of engineer is associated in our minds with ideas of more than average ability and patient application. Most of us who pursue the ordinary walks of life upon the level plain must be content with looking upward at this pinnacle, and many of us must even employ a good glass to catch a glimpse of the engineer who has reached and is still at labor upon the summit. But if the average business men cannot find it convenient to climb the heights, they can at least take pleasure in welcoming those who have done so when they come down to the level at the base; and so, gentlemen, it gives me pleasure to speak in the name of the business men generally, and particularly in the name of the four hundred and fifty business and professional men who constitute the Denver Chamber of Commerce and Board of Trade. Your profession and the interests of the City of Denver are closely allied. The fixing of our grades, the establishment of our sewers, the supplying of pure water, the laying of our irrigating canals, the building of our bridges, without which the City of Denver would not have reached the place of some importance that it now occupies—these are the works of the engineer. Wherever the miner delves far beneath the surface of the earth to procure the ores for our great smelting establishments, there the engineer must be. Wherever the steel arteries of commercial traffic climb into the clouds to bring those ores of gold and silver to our doors and take back the products of our markets and our farms, there the engineer has first been. Since the inception in Denver of the first narrow-gauge railroad in the world for general traffic, our Colorado engineers have overturned many former conceptions, perhaps not of the engineers as a profession, but certainly of the financiers, and have demonstrated their ability to construct practicable lines of railroad wherever there was the money to pay for them. It is entirely practicable, and some of you gentlemen will live to see the day when the tourist may leave Denver after breakfast in the morning and dine on the summit of Long's or Pike's Peak after having covered the entire distance and elevation by rail. Colorado is, and will long continue to be, the scene of some of the most novel and grand features of engineering skill upon this continent, and so it seems to us that your meeting in its metropolis, from which you may be escorted to some of the more easily reached places showing the work of our Colorado engineers, is particularly appropriate. We take much pride in the work of our local profession. We rejoice with them in the opportunity that you have given them to present their works for the

inspection of the masters of the profession, and we join with them with pleasure in endeavoring to make your visit to this city entertaining. We do this with all the more pleasure, because all but the younger portion of our people here were once emigrants from the principal States from which you hail. Your cities and your farms have all contributed to our own cosmopolitan population, and so we feel, gentlemen, that you are not strangers to us, but old friends who have known us in our former home and have kindly come out here to visit us in our new. We feel, gentlemen, that whatever benefits may result to you as a body from the deliberations of this annual gathering, will in due time be applied to the advancement of our own City and State, and we feel also that if you obtain any benefit whatever from an examination of our own works and the works of our local engineers, it will be of a greater benefit to ourselves; for we think that we are inhabiting a little the best part of this grand old Union of States, and if the entire population of the country cannot come and enjoy it with us, we would at least like to pay for our special privilege by contributing something to the scientific knowledge and advancement of those who live elsewhere.

We welcome you gentlemen, as men whose names are associated with some of the grandest works of science of the modern world. We welcome you to a city at the apex of our continent, and but a few days ride beyond the line which divides its orient from its occident. We welcome you to its beauties, to its healthfulness, to its resources, to its youthful vigor, to its past works, and to our unfaltering faith and trust in its future.

The Chairman, Mr. R. B. Stanton.—On behalf of the Society I would introduce Mr. George S. Greene, Jr., Director of the Society, who will now address you.

Mr. George S. Greene, Jr., Director Am. Soc. C. E.—On behalf of the American Society of Civil Engineers I beg leave to accept the kind and generous welcome which the business men of this thriving, handsome city have tendered us. We, whose part it is in life to assist and to guide business men in developing nature for the benefit of mankind, come here in order that we may better know and understand the wonderful gifts of nature which you possess, and the scarcely less wonderful uses and purposes to which you and our brethren here have adapted them. We are met on all sides with cordial, generous welcome, and I would, sir, express to you our thanks for such a welcome. But words fail me to express adequately and properly our pleasure and gratification in being here, and our high appreciation of such a welcome as we have received; but I can and do assure you, sir, that we shall long and agreeably remember our reception, here at the very base of the grand old Rockies, in this city, great already and surely destined

through your faith in yourselves and in your work, before long to rank among the greatest—Denver.

The Chairman, Mr. R. B. STANTON.—We shall now have the honor of listening to the annual address of our President, Col. Henry Flad, of St. Louis.

The President, Mr. HENRY FLAD.—Ladies and Gentlemen: It is the duty of the President of this Society to deliver annually at the Convention an address, and I have prepared such an address, but, owing to a sore throat, I have to ask a Member of the Society, my friend, Mr. Robert Moore, of St. Louis, to read that address for me, and he has kindly consented to do so.

Mr. ROBERT MOORE, M. Am. Soc. C. E.—I know it is impossible for any of you to more deeply regret the announcement that has just been made than I do, and I very much fear it will be difficult for you to keep from holding me responsible for the sore disappointment you must feel at the substitution of any other voice for that of our revered President. I can only hope that you will bear as patiently as you can with this, which is our common misfortune.

[Mr. Moore then read the President's address, which is published in the Transactions for this month.]

THIRD SESSION.

SATURDAY, JULY 3D, AFTERNOON.—The meeting was called to order at 14:50 o'clock, Mr. ROBERT B. STANTON in the chair.

The CHAIRMAN.—I have an invitation here that I will read.

To the President and Members of the American Society of Civil Engineers, Denver, Colorado.

GENTLEMEN,—At a time that will best suit your convenience, we desire to show you the operation of our Electric Railway, believing that it will greatly interest you from both engineering and scientific points of view. It involves principles claimed by no other system, and we have it in practical operation.

If we may suggest a time for your visit it will be at the close of your afternoon session to-day. The place is 15th street, crossing of Glenarm.

We are, very respectfully,

Your obedient servants,

THE U. S. ELECTRIC CO.
By WM. N. BYERS,
President.

Mr. GEO. B. NICHOLSON, M. Am. Soc. C. E.—I move that the invitation be accepted, with thanks.

The motion was carried.

Invitations to visit the Argo Smelting Works and the Grant Smelting Works were presented and accepted.

A paper by A. M. WELLINGTON, M. Am. Soc. C. E., on "The American Line from Vera Cruz to the City of Mexico, with Notes on the Best Methods for Surmounting High Elevations by Rail," was read by the author.

The chair was taken temporarily by Mr. JACOB BLICKENSDERFER, M. Am. Soc. C. E., during the reading of the above-named paper.

At the conclusion of the paper a recess was taken till evening.

FOURTH SESSION.

JULY 3D, EVENING.—Mr. ROBERT B. STANTON in the chair.

An invitation was presented from the City Engineer of Denver, Mr. H. C. Lowrie, C. E., to visit the City Hall and inspect plans and specimens of city engineering work and appliances. The invitation was accepted for the morning of July 5th, when a large number of Members met the City Engineer, and under his escort examined the sewerage and other city public works.

The paper on "The American Line from Vera Cruz to the City of Mexico, with Notes on the Best Methods for Surmounting High Elevations by Rail," by A. M. WELLINGTON, was discussed by Messrs. Robert Moore, William Watson, J. B. Johnson, H. H. Filley, Robert B. Stanton, H. P. Taussig, M. Cohen, C. M. Woodward, Francis D. H. Lawler, and A. M. Wellington.

A note by J. FOSTER FLAGG, M. Am. Soc. C. E., describing "A Remarkable Rainfall in the West Indies," was read.

FIFTH SESSION.

MONDAY, JULY 5TH, MORNING.—Mr. ROBERT B. STANTON, Chairman, presiding.

A paper by Professor ALEXIS A. JULIEN, on "Building Stones," was read.

On motion, the business meeting was then held. [For the record of the business meeting see page 85 of the current Proceedings.]

At the close of the business meeting of the Society, the session of the Convention was resumed, Mr. ROBERT B. STANTON, Chairman, presiding.

Mr. ROBERT MOORE.—Mr. President: I move that we proceed to the appointment of the Nominating Committee.

The motion was seconded.

At the request of the Chair, the Secretary read the provisions of the By-Laws referring to the appointment of a Nominating Committee.

The motion of Mr. Moore was carried.

The CHAIRMAN.—How shall this committee be appointed?

Mr. GEORGE S. MORISON.—I move that it be appointed by nomination.

The motion was carried.

After nomination, Mr. Charles Macdonald, of New York, Past Director of the Society, was elected as Chairman of the Committee.

After discussion it was determined that nominations should be continued as long as any Members desired to make nominations, and then that the additional members of the committee should be chosen by a vote by ballot. Seven nominations were made, and a vote was taken by ballot. The Nominating Committee elected is as follows:

Charles Macdonald, of New York, N. Y.; B. M. Harrod, of New Orleans, La.; Robert B. Stanton, of Denver, Colo.; Desmond FitzGerald, of Brookline, Mass.; H. Stanley Goodwin, of Bethlehem, Pa.

Sixth Session.

July 5th, Afternoon.—Mr. Robert Moore, M. Am. Soc. C. E., in the chair.

A paper on "Laying Masonry in Cold Weather," by Alfred Noble, M. Am. Soc. C. E., presented through the Committee on Compressive Strength of Cements, was read and discussed by Messrs. Collingwood, Morison, Stanton, Eliot C. Clarke and Bogart.

A paper by Edward B. Dorsey, M. Am. Soc. C. E., supplementary to the paper published in Transactions for January, 1886, on "English and American Railroads Compared," was read and discussed by Messrs. Collingwood, Stanton, Woodward, Wellington, Chanute, Morison, Vose (by letter), and Cohen.

A paper on the "Compressive Strength of Steel and Iron" by Charles A. Marshall, M. Am. Soc. C. E., was read and discussed by Mr. Collingwood.

A paper by Charles E. Emery, M. Am. Soc. C. E., on a "Novel Application of the Polar Planimeter" was read.

The paper on "The Steamship America," by Robert Gordon, M. Am. Soc. C. E., published in Transactions for May, 1886, was discussed by Messrs. Morison and Woodward.

The President, Mr. Henry Flad, offered the following resolutions; these were seconded by Vice-President Thomas C. Keefer, and were carried:

Resolved, That the American Society of Civil Engineers in Convention assembled, desires to express its appreciation of the courtesies extended to it during the visit of the Society to Colorado, and particularly to the Denver Society of Civil Engineers and its local Committee; to the Chamber of Commerce; and the Committee of Citizens of Denver.

The pamphlet prepared by the Denver Society has been a great aid in understanding the wonderful development of this beautiful City and this remarkable State.

Resolved, That the Secretary of the Society be requested to properly acknowledge the courtesies extended by the railroads in Colorado, the Union Pacific and the Denver and Rio Grande.

Resolved, That the thanks of the Convention be and are hereby extended to the Chairman of the Convention, Mr. Robert B. Stanton, M. Am. Soc. C. E., who, both as such Chairman, and as the Chairman of the Local Committee, has done so much to make this a memorable Convention in the annals of the Society.

Seventh Session.

Wednesday, July 7th, Evening.—Mr. Robert B. Stanton in the chair.

A paper on "The Davis Crevasse Levee," by S. F. Lewis, M. Am. Soc. C. E., was read.

The following 103 Members were in attendance at the Convention: E. C. Appleton, Ashland, Neb.; John W. Bacon, Danbury, Thomas S. Bishop, New Britain, Conn.; John Bogart, New York City; Wm. F. Booth, Poughkeepsie, A. Bryson, Brooklyn, N. Y.; A. Bonzano, Phœnixville, Pa.; Clifford Buxton, Toledo, Ohio; Edward Baumann, Chicago, Ill.; William R. Belknap, Louisville, Ky.; George Burnet, Jr., St. Louis, John F. Barnard, St. Joseph, Mo.; Henry I. Bliss, La Crosse, Wis.; Charles Blackwell, J. Blickensderfer, Omaha, Neb.; Eliot C. Clarke, Boston, Mass.; J. James R. Croes, New York City; William B. Cogswell, Syracuse, N. Y.; Francis Collingwood, Elizabeth, N. J.; Mendes Cohen, Baltimore, Md.; William W. Card, Pittsburgh, Pa.; O. Chanute, Kansas City, Mo.; David W. Cunningham, Grandin, Dak.; B. L. Crosby, Rulo, Neb.; Joseph P. Davis, S. B. Downes, New York City; F. de Funiak, Louisville, Ky.; Thomas Doane, Crete, Neb.; E. W. Eckert, Massillon, Ohio; George D. Emerson, Rolla, Mo.; Howard N. Elmer, St, Paul, Minn.; Robert Fletcher, Hanover, N. H.; Charles A. Ferry, New Haven, Conn.; Clark Fisher, Trenton, N. J.; Henry Flad, St. Louis, S. Waters Fox, St. Joseph, Mo.; H. H. Filley, Mexico, Mexico; Bryant Godwin, G. S. Greene, Jr., New York City; Edward B. Guthrie, Buffalo, N. Y.; Charles E. Goad, Montreal, Canada; Charles E. Greene, Ann Arbor, Mich.; Carl Gayler, St. Louis, Mo.; B. H. Greene, Helena, Mont.; Arthur H. Howland, Boston, Mass.; William G. Hamilton, William J. Haskins, William R. Hutton, New York City; James D. Hawks, F. B. Howard, Detroit, Mich.; Rudolph Hering, Chicago, Ill.; M. L. Holman, St. Louis, Mo.; H. V. Hinckley, Topeka, Kan.; John B. Johnson, St. Louis, H. F. Juengst, St. Joseph, Mo.; George A. Kimball, Somerville, Mass.; Thomas C. Keefer, Ottawa, Canada; Geo. W. Kittredge, Columbus, Ind.; Edward C. Kinney, Omaha, Neb.; Charles Latimer, Cleveland, Ohio; William H. Lotz, Chicago, Ill.; W. S. Lincoln, St. Louis, Mo.; Charles Macdonald, Thomas C. Meyer, George S. Morison, New York City; James R. Maxwell, Newark, Del.; David E. McComb, Washington, D. C.; John J. McVean, Ionia, Mich.; Henry G. Morse, Youngstown, Ohio; M. W. Mansfield, Indianapolis, Ind.; Robert E. McMath, Robert

Moore, St. Louis, Mo.; Albert F. Noyes, West Newton, Mass.; George B. Nicholson, Cincinnati, Ohio; John Nichol, Chicago, Ill.; F. S. Odell, New York City; John F. O'Rourke, Prairie du Chien, Wis.; Franklin C. Prindle, East Orange, N. J.; Joseph R. Richards, Boston, William Roberts, Waltham, Thomas F. Richardson, Wilmington, Mass.; David Reeves, Philadelphia, Pa.; L. W. Rundlett, St. Paul, Minn.; Andrew Rosewater, Omaha, Neb.; George S. Rice, Georgetown, Colo.; George F. Swain, Boston, Mass.; Robert B. Stanton, Denver, Colo.; Stevenson Towle, New York City; Alfred W. Trotter, Bristol, Tenn.; John G. Van Horne, New York City; William Watson, Boston, Mass.; James R. Wardlaw, F. W. Watkins, A. M. Wellington, William H. Wiley, New York City; Charles D. Ward, Jersey City, N. J.; J. W. Walker, Pittsburgh, Pa.; Fred. C. Weir, Cincinnati, Ohio; Thomas J. Whitman, C. M. Woodward, St. Louis, Mo.; John F. Wallace, Keithsburg, Ill.; J. A. L. Waddell, Council Bluffs, Iowa; and Samuel H. Yonge, Kansas City, Mo.

Sixty-seven ladies of the families of members accompanied them on the occasion of this Convention.

On Tuesday morning, July 6th, by invitation of the Union Pacific Railroad, Mr. J. K. Choate, Superintendent, an excursion was made to the town of Greeley, north of Denver, where the improvement of desert lands by extensive irrigation was witnessed.

On Wednesday, in accordance with the same invitation, an excursion was made through the Clear Creek Cañon to Georgetown, Colo., and to the high loop line beyond that city. After dinner at Georgetown the party returned to Denver the same evening.

On Thursday, by the same kind invitation, a trip was made over the Denver and South Park Railroad to Leadville. The three summits passed on this line are respectively 10,000, 11,498 and 11,325 feet above the level of the sea.

The evening and night of Thursday were spent at Leadville.

On Friday morning, by invitation of the Denver and Rio Grande Railway, Mr. W. S. Jackson, Receiver, Mr. R. E. Ricker, General Superintendent, the party left Leadville and proceeded to Salida, thence West through Marshall Pass, and returned through the Grand Cañon of the Arkansas and the Royal Gorge to Pueblo and Colorado Springs, and arrived at Manitou on Friday evening, spending Saturday and Sunday at that place. The ascent of Pike's Peak was made by a number of Members.

On one of the evenings during the stay at Denver, a reception at the hotel gave an opportunity for meeting many citizens.

On one of the mornings, by invitation of a number of gentlemen, the Members and visiting guests were driven about Denver and its suburbs in the private carriages of their hosts.

The party from the East left the Grand Central Depot, New York, at 10 o'clock of the morning of June 29th, in a special train of two sleeping cars of the New York Central Sleeping Car Company, and two hotel cars of Pullman's Palace Car Company. At Chicago an additional Pullman hotel car was added, and at Burlington a Pullman sleeper, with the St. Louis Members, joined the train. The route westerly was by the Hudson River to Albany, the New York Central to Buffalo, the Lake Shore and Michigan Southern to Chicago, and the Chicago, Burlington and Quincy to Denver. Chicago was reached at 10 o'clock on the morning of June 30th. Four hours and a half were spent at Chicago, and the train reached Denver at eight on the morning of Friday, July 2d.

Returning, the party left Colorado Springs on the evening of July 11th, and proceeded by the Denver and Rio Grande Railway to Denver, thence by the Kansas Pacific Division of the Union Pacific to Kansas City, thence the St. Louis car returned to that city by the Missouri Pacific. The main train proceeded by the Hannibal and St. Joseph Railroad to Quincy, by the Chicago, Burlington and Quincy to Chicago, by the Michigan Central and Canada Southern to Buffalo, and by the New York Central and Hudson River to New York, arriving Wednesday evening, July 14th.

Throughout the whole trip, and also during the excursions in Colorado, every suitable courtesy and attention was given to the Society by the officers of and all connected with the railway lines. While at Denver, the Local Committee, the Members of the Denver Society of Civil Engineers, the Committee of the Chamber of Commerce, and the citizens of Denver were constant in efforts to aid the Society in the purposes of the Convention.

MEETINGS OF THE SOCIETY.

June 16th, 1886.—The Society met at 20 o'clock, Past Vice-President William H. Paine, in the chair; John Bogart, Secretary.

A paper by F. S. Odell, M. Am. Soc. C. E., on "The Water Supply and Sewerage of the Lawrenceville (N. J.), School," was read by the author and discussed.

July 5th, 1886.—(Business meeting during the Annual Convention at Denver, Colo.) The President, Henry Flad, in the chair; John Bogart, Secretary.

The President.—Are there any communications received since the last regular meeting ?

The Secretary read the following letter:

June 26th, 1886.

HENRY FLAD, Esq.,

President of the American Society of Civil Engineers.

SIR,—Referring to the communication addressed to you by Mr. John R. Whitley in January last, I desire, as President of the American Exhibition to be held next year in London, to confirm the cordial invitation extended to you and the Members of the Society of Civil Engineers by Mr. Whitley, on behalf of the Board of Direction of our Exhibition in London, and I shall be pleased to learn that the same will be accepted by yourself and a large number of your colleagues.

Yours very respectfully,

E. B. WASHBURNE,
Of Illinois.

The PRESIDENT.—What is your pleasure with reference to this communication ?

Mr. J. J. R. CROES.—I move that it be laid on the table, and that the Secretary be instructed to express to the chairman of that exhibition the thanks of the Society for their kind invitation.

The motion was seconded by Mr. R. B. Stanton and carried.

The PRESIDENT.—Are there any communications to be read from Members present? If not, the next thing in order will be communications from the Board of Direction.

The SECRETARY.—I have none, sir.

The PRESIDENT.—Are there any committees ready to report?

The SECRETARY.—I have, Mr. President, one or two written reports, and then there are other committees whose chairmen are present. The first is the report of the Committee upon Uniform Standard Time, which I have here.

The PRESIDENT.—Read it, please.

The Secretary read the report of the Committee as follows:

REPORT OF THE SPECIAL COMMITTEE ON STANDARD TIME.

July 5th, 1886.

The Committee on Standard Time desire to report progress.

In the report presented at the Annual Meeting of the Society in January last, among other things it was stated that the Canadian Pacific Railway Company had publicly announced its intention to adopt the twenty-four hour system at an early day. Since then the watches of employees of the Company, and all stationary clocks, have been adapted to the new notation, and the public along the line of railway have gratuitously been furnished with new dials by the Company. On or about the 1st of July, the Canadian Pacific Railway will be opened from ocean to ocean for public traffic, and trains will then be run on the twenty-four hour system. The time tables for operating the line on the changed plan are prepared. For some months back the Canadian Pacific telegraph has been worked on the twenty-four hour system. On the

other side of the globe the entire net-work of telegraphs of the Eastern Telegraph Company has been operated with advantage on the twenty-four hour plan. This Company's lines extend from England to Egypt, South Africa, India, China, Japan, Australia and New Zealand.

The Smithsonian Institution desiring to co-operate in the important movement of Time Reform, is about to publish, for diffusion in all quarters of the globe, A Memoir on Time Reckoning for the Twentieth Century. The Committee has been furnished with a copy of this paper, which, with the permission of the Smithsonian Institution, may be read to the Convention.

SANDFORD FLEMING, *Chairman.*

Mr. CROES.—I move that the report be accepted and the Committee continued.

The motion was carried.

The PRESIDENT.—Is there any report from the Committee to consider Changes in Organization of the Society?

Mr. A. M. WELLINGTON.—I believe that there is no report of that Committee ready.

Mr. ROBERT MOORE.—I would like to ask if there is any probability of a report, if not, I would like to follow it by a motion that the Committee be discharged.

The motion was seconded and carried.

The PRESIDENT.—Is the Committee to consider a Plan for Creating a Library for Joint Use, ready to report?

Mr. GEORGE S. MORISON.—I believe I am a member of that Committee, but I have not met with it for several months. The Committee has held two or three meetings. It is not, I believe, prepared to make a report of any kind. That is all that I can say. The Committee is a very complicated one. There is a Committee appointed by this Society; there are Committees appointed by several other Societies; these Committees met together and appointed for some special purposes a Joint Committee, composed of one member of the Committee of each Society. So far there have been two or three meetings, at which very little has been done. It is a matter, that if done at all, will take a great deal of time. As matters now stand, there is absolutely nothing to say in the way of a report.

A motion was offered that the Committee be discharged.

Mr. CROES.—Does the gentleman ask that the Committee be continued, or has he any suggestion to make?

Mr. MORISON.—I should prefer to make no request of any kind. It should be remembered that there are these other Committees appointed by other Societies, which Committees, so far as any action has been taken, have been acting together, and it might be unpolite to the other Societies to discharge this Committee.

Mr. JOHN BOGART.—I would suggest that the Committee be continued. I don't think any harm will be done.

Mr. CROES.—I move that the Committee be continued, and the verbal report of the member present accepted.

The motion was carried.

The PRESIDENT.—There is a Committee to consider the Proper Relation to Each Other of the Sections of Railway Wheels and Rails. Is that Committee ready to report?

Mr. A. M. WELLINGTON.—On behalf of the Chairman of that Committee, Mr. H. Stanley Goodwin, who is not present, I have to report progress, and state that the subject is under consideration by the individual members of the Committee. It has been arranged, owing to the widely separated residences of the Committee, that the simplest way will be that each one of the members of the Committee shall prepare a paper for submission to the Society, individually, which can then be discussed by the members of the Committee, and after that a report of the Committee be prepared. Therefore the Committee ask to be continued.

Mr. ROBERT E. MCMATH.—I move that the Committee be continued.

The motion was carried.

The PRESIDENT.—There is a Committee which is to report on the Compressive Strength of Cements, and the Compression of Cements and the Settlement of Masonry.

The SECRETARY.—The Chairman of the Committee, Mr. Collingwood, will be here directly. I suggest that that be passed over temporarily.

The PRESIDENT.—We can pass it over temporarily, and take it up when Mr. Collingwood returns.

Mr. ROBERT MOORE.—I would like to say that in making the motion to discharge the Committee on the Relations of the Various Engineering Societies, it was not to dismiss the subject from the consideration of the Society or the Convention, but because, as I understood, somewhat indirectly, the Committee had no chairman, and was in a condition from which we could not expect any report. I think the question is a very important one, and should be thoroughly discussed. I think a discussion by this Convention, which would elicit all the views on the subject is a very important matter for this Convention to take up.

The PRESIDENT.—That matter can be taken up when we come to new business. Unfinished business is next.

The SECRETARY.—No unfinished business is presented.

The PRESIDENT.—Then comes new business.

Mr. ROBERT MOORE.—I have no suggestions myself to offer. I should like very much to hear from the members of the Committee who have given the matter consideration, and to know their individual views, which, I have no doubt, they have formed quite definitely. I have impressions upon the subject, but they are not crystallized into positive convictions, and I would like to have more light on it, and desire very much to hear from the members of the Committee.

Mr. A. M. Wellington.—So far as I am individually concerned, as one of the members of the old Committee, I think I have given my views in a paper distributed to the Members of the Society. I may say, I think for all the members of the Committee, that a large part of the difficulty which came in was in regard to questions of detail, and the difficulty in coming to any definite understanding on questions of detail was, in a large part, on account of their scattered residences. When they did have meetings, which was only on two occasions, the members were generally so busy that they could not devote any great amount of time to a consideration of the question. For myself, individually, I still retain exactly the views that I expressed before, and I shall be very sorry indeed if something is not done to enlarge the scope of the Society in the general direction which has been suggested and which was contemplated by the resolution appointing the Committee. Nevertheless, so far as I am individually concerned, it is nothing to me. The Society suits me very well as it is. I am perfectly willing that the Society should try the experiment of letting matters go on as they are.

Mr. Charles Macdonald.—As one of the members of that Committee, I may say that every member of it had the same feeling in regard to the importance of some action being taken by this Society whereby a unity of interest and feeling might be engendered with all the societies outlying from New York. We had two meetings in New York, and the majority of us came to a conclusion in regard to what was best to be done. By reason of certain lapses and misunderstandings, which it is not necessary here to detail, those conclusions were not acted upon. I think myself that, perhaps, if another Committee were appointed, and the whole subject taken up again, it would be well. The view that I had personally, was that it would be injudicious to attempt any organic change in the American Society of Civil Engineers whereby a connection between the different societies or clubs existing in differents parts of the Union with the parent society might be brought about. I say that I thought it was injudicious to attempt any such legislation. In the first place it would take a long time to make a change in our Constitution which would bring that about. Then it was not altogether certain that if we decided upon any particular form of legislation it would be acceptable to the members of the different clubs. It was a very delicate thing I found to take action of that kind, but it seemed to me that a practical union or community of action and interest might be brought about by adopting some method for the publication of Transactions and disseminating them broadcast, not only among the Members of the Society itself, but the members of all the clubs. That would not require any organic change in our own body. It would not be asking the members of the clubs to become members of the Society in any sense. That might not be agreeable to them. It would not make it necessary for us to change our standard of admission, nor our methods of electing mem-

bers. But it would be doing all that we are organized for, and that is, the dissemination of professional information. It would be opening the doors of the Society for the receipt of all papers that were presented by members of local clubs, the publication by the Society of such papers, and their discussion and practical incorporation into the Transactions of the American Society of Civil Engineers. That would have the indirect effect of making all the members of the local clubs and societies perfectly aware of what was being done, and of the benefits arising from being members of the American Society of Civil Engineers. Without offering them any special official inducements, it would, I believe, have the effect of so impressing them with the importance of belonging to the parent society that it would increase our membership very largely. At the same time it would have the immediate effect of securing for the Society the very best technical papers that were presented, not only by our own Members, but throughout all the different clubs in the country. That was my view and that of some other members of the Committee, and I feel very certain that some action ought to be taken by the Society towards bringing about some such end as that, and that a new Committee ought to be appointed. If a judicious selection is made, I believe that a report may be expected from such a Committee which might be acted upon at the next regular meeting.

Mr. Morison.—Might it not be worth while to carry out a portion of Mr. Macdonald's suggestion without carrying out the whole? Why would it not be well to encourage the expression of individual opinion, as far as is possible, between now and the next annual meeting, with the understanding that a committee is to be appointed at that meeting to consider this subject? The Board of Direction could very well invite the different Members of the Society to contribute their opinions in writing on this subject, with the express understanding that such of those opinions as were thought best should be published in the Transactions of the Society; or, better, in some special form. In that way the subject could be pretty well canvassed without the immediate appointment of a committee. Time would be given to consider what could be best done at the next general meeting of the Society. I would therefore move that this subject be referred to the Board of Direction, with the request that they invite written communications from the Members of the Society, and that the Board of Direction shall report on this subject at the next annual meeting, with the expectation that a special committee be appointed at that time.

The motion was seconded.

Mr. Morison.—Before the matter goes any further, I should like to add to the motion a provision that the Board of Direction may invite communications from the different engineering clubs throughout the country.

Mr. Wellington.—In seconding Mr. Morison's motion, which seems

to me one of the wisest moves in a general way that can be taken for reaching some definite conclusion, I would suggest an addendum to it, and that is whether it would not be expedient that one or more (two or three possibly) special meetings of the Society should be held after these reports have been submitted, for their discussion. If our Committee could have met conveniently and it could be certain that all the members of the Committee felt a real interest in the matter, which perhaps one or two did not, although I think they did, it might not have been impossible for us to have reached a conclusion. But it is a frequent difficulty of committees that their members are scattered, and very often one or two or three or four take little interest and all the real work falls on one or two. By calling special meetings of the Society, those interested would attend, those who were not would stay away, and I think it would result in enabling a conclusion to be arrived at which would be more definite.

The President.—Are you ready to vote on Mr. Morison's proposition? If I understand right, the motion is that the Board of Direction should be instructed to request the Members to state their views in writing in regard to the subject matter, and also members of the other societies interested.

Mr. Morison.—That the views so expressed be printed and distributed among the Members of the Society, and the matter reported on at the next annual meeting.

Mr. Croes.—I would like to know whether Mr. Morison intends that all the individual communications should be published and spread before the Society, or that they should be edited?

Mr. Morison.—In such a case as this there is always some probability of communications being sent in which neither the writer nor any one else expects to be printed. I think the understanding should be that the Direction should give to the Society what is virtually the whole, but should exercise the privilege, which they always ought to, of editing.

Mr. Macdonald.—The Direction, as I understand, are to take this matter in hand now and get up the information which is in question and then let it be laid before the annual meeting.

Mr. Morison.—I think it is desirable that it should be in the hands of members a sufficient time to read it before the annual meeting. I do not think it would be practicable with the annual meeting only six months off to have any action before the annual meeting, but I think a subject of this kind ought to be in print and in the hands of the Members.

Mr. McMath.—If the Board of Direction have no authority to submit to the Society for consideration their recommendations in the matter, I would move that they be instructed to do that.

The President.—Mr. McMath proposes that the Board of Direction should be instructed to state their own views in regard to the matter.

Mr. Morison.—It seems to me that the Board of Direction would have the power to do that at any rate, and that we should expect them to do it. I think we might fairly leave that to the judgment of the Direction.

Mr. McMath.—I just threw that out as a suggestion. It is desirable at least, after the Board of Direction has all this matter in hand—they are supposed to read it, which all the Members will not do—it is desirable that they should crystallize the whole matter into the shape of some definite recommendation, and then let the Society adopt or reject the specific measure or an alternative measure proposed by them.

Mr. Morison.—I am willing to accept the amendment if it be put in this form: "With such conclusions as they desire to lay before the Society."

Mr. McMath.—That meets my views exactly.

The Secretary.—I suggest, Mr. President, if it be agreeable, that Mr. Morison be requested to dictate a concise resolution covering these points.

Mr. Morison then dictated to the stenographer the following resolution:

"That this subject be referred to the Board of Direction, with the request that they invite written communications from the Members of the Society, and from the different engineering clubs throughout the country, and that these communications be edited under the direction of the Board, and their substance printed and distributed among the Members of the Society. And that the Board shall make a report at the next annual meeting, with such conclusions as they desire to lay before the Society, and with the expectation that a special committee will be appointed at that time."

The resolution was adopted.

The Secretary.—The Chairman of the Committee on the Compression of Cements is here now, sir.

The President.—If Mr. Collingwood is ready to report we shall be glad to hear from him.

Mr. F. Collingwood, Chairman, presented the report.*

Mr. Collingwood.—I have another paper furnished by Mr. Alfred Noble, M. Am. Soc. C. E., showing results in setting masonry in very cold weather, which the Secretary thinks should be presented.

The Secretary.—That is a technical paper, and we are now dealing with the reports of Committees. I suggest that Mr. Noble's paper be read in one of the Convention Sessions.

Mr. McMath.—I move that the report be accepted, and that the Committee be continued.

The motion was carried.

Mr. C. M. Woodward.—Under the head of new business, I desire to

*This report will be published in a future number of Proceedings.

submit to this Society the following resolution. It will be seen that it is in the interest of economy and perfected work.

"*Resolved*, That this Convention submits to the Committee in charge of arrangements for the next Annual Convention of the Society, the following suggestions:

"*First.*—To print beforehand all papers to be presented at the Convention, including such papers already presented, but not yet printed in the Transactions, as the Committee may select, and to furnish each Member with advance sheets of the same at least three weeks before the meeting.

"*Second.*—To arrange a programme for the Sessions of the Convention, allowing authors of papers ten minutes each in which to present the abstracts, or to call attention to salient points in their papers.

"*Third.*—To invite Members to prepare discussions, and to assign a definite amount of time to the discussion of each paper, proportioned to the probable interest and demand.

"*Fourth.*—To instruct the presiding officer at the meetings to strictly observe the following rules:

"(*a*) To allow the author of a paper to close the discussion upon the same, either at the meeting or in print, as may be most convenient.

"(*b*) To allow no one more than five minutes, nor the floor a second time, in the discussion of a paper, except by unanimous consent.

"(*c*) To give the preference in a discussion to those who have signified their desire to participate.

"(*d*) And to rigidly carry out the pre-arranged programme, taking up each paper at the hour assigned, and leaving additional or miscellaneous discussions for an hour reserved for that purpose."

Mr. Bogart.—I desire to second the resolution. One of the great troubles in managing the business of the Convention, to the Secretary and to the Committee in charge of it, is the work that is covered by this resolution. We have tried something like this before, but there are several provisions in this resolution which cover points that made our previous trials not thoroughly effective. In particular I refer to one, which is that papers which have been presented to the Society before a Convention, but which have not yet come to be printed in the Transactions on account of other papers being in advance of them, may be considered as Convention papers. Our trouble has been in regard to this matter, that the gentlemen who promise papers for Conventions, and promise them indubitably with good faith, and with the intention to get them in the proper length of time before the Convention, generally do not do it. The result is that the papers come in at the very last moment, and that there is not time to get them printed and circulated properly for discussion. Therefore I take pleasure in seconding the resolution.

Mr. Croes.—This is a business meeting of the Society. This is not the Convention. Now, if the resolution is to be offered as a resolution of the Convention, it wants to be offered after the business meeting has adjourned. If it is a resolution passed by the Society at this time it wants to be so expressed.

The Secretary.—Will Mr. Croes suggest the desired modification?

Mr. Croes.—The resolution begins: "*Resolved*, That this Convention submits."

Mr. Woodward.—I think the criticism is a good one. It seems to me the point is well taken, and if the Society will allow me, I will change the word "Convention" to "Meeting."

Mr. Collingwood.—It occurs to me that there might be an amendment to these suggestions. In the practice of the Institution of Engineers they are in the habit always of requiring an abstract for reading at a meeting. Very many of the papers that are presented here, if properly abstracted, the salient points being given, omitting figures except as illustrations, would be heard with interest, whereas we get tired out before they are finished. A properly arranged abstract, which could be quickly printed and circulated, would not necessitate the printing of the original paper before the meeting, and then with properly arranged illustrations, it would add greatly to the interest. I would like to make that as an amendment to these suggestions.

Mr. Woodward.—I will accept that amendment if my seconder will allow, and suggest that it be added properly to the wording of the resolution.

The resolution was then amended so that the first line should read:

"*Resolved*, That this meeting submits," etc., etc.

Also that the first section of the resolution should read:

"*First.*—To print beforehand abstracts of all papers to be presented at the Convention, including abstracts of such papers already presented, but not yet printed in the Transactions, as the Committee may select, and to furnish each Member with advance sheets of such abstracts at least three weeks before the meeting."

The resolution thus amended was adopted.

Mr. Robert Moore.—As one part of the business of this Convention is the appointment of a Nominating Committee, I have a resolution to offer on that subject. As you are all aware, probably, the By-Laws require that at the Annual Convention a Nominating Committee of five shall be appointed, and as, prefatory to explaining the purpose of this resolution, it may be well to call attention to the fact that this Society is a corporation under the laws of the State of New York, and that, according to the Constitution of the Society, a majority of the Board of Direction must be residents of the State of New York, where the Society has its legal domicile. Of course the Resident Directors, who are charged by law and custom with the conduct of the business of the Society,

should be chosen with great care; not only those who are familiar with the business of the Society, but those whose engagements would permit them to give proper attention to that business, so that it is extremely important that those who are charged with the business of the Society shall be chosen with the utmost care, and it is for that purpose that at the suggestion of a number of the older Members of the Society, and notably at the suggestion of our Past President, Mr. Don. J. Whittemore, this resolution is brought forward:

"*Resolved*, That the Chairman of the Nominating Committee shall be a Resident Member, who is a past Officer or Director of the Society."

The last qualification is put in from the fact that the service of any one as an officer or director of the Society will no doubt have acquainted him with the necessities of the position in such a manner that he will be more likely to suggest a good nomination than one who has not had that experience. I think it will conduce very greatly to wise action in this matter, and perhaps avoid some errors that have been made through ignorance, growing out of the fact that the members of the Nominating Committee were persons who did not know the requirements of the case, who did not know the persons from whom the Resident Directors should be chosen, rather than from any other reason. I therefore make this motion.

The motion was seconded and carried.

Mr. M. Cohen.—I move that this meeting of the Society do now adjourn.

The motion was carried.

LIST OF MEMBERS.

ADDITIONS.

MEMBERS.		Date of Election
ATWATER, ALMON BYRON	Superintendent Chicago and Grand Trunk and Detroit, Grand Haven and Milwaukee R'ys, Detroit, Mich	May 5, 1886.
BRACKENRIDGE, WILLIAM ALGERNON	Principal Assistant Engineer Brooklyn and Long Island Cable R'y, Brooklyn, N. Y	June 2, 1886.
EATON, FREDERICK	Consulting Engineer Los Angeles City Water Co., Los Angeles, Cal.	May 5, 1886.
FULLER, EUGENE FREDERICK	18 Wall street, New York City	May 5, 1886.
GILLHAM, ROBERT	Chief Engineer Inter-State Rapid Transit R'y, Shiedley Building, Kansas City, Mo	June 2, 1886.
HOWLAND, ARTHUR HENSHAW	United States Hotel, Boston, Mass.	June 2, 1886.
HOXIE, RICHARD LEVERIDGE	Captain Corps of Engineers, U. S. A., Montgomery, Ala	June 2, 1886.
HUSON, HERBERT SHERMAN	Assistant Engineer Yakima Div. Northern Pacific R. R., Ellensburg, Wash	June 2, 1886.
JACKSON, CHARLES EDWARD	Principal Assistant Engineer Brooklyn Elevated R'y, 122 East Nineteenth Street, New York City	June 2, 1886.
LAWTON, WILLIAM HENRY, JR.	20 Bellevue avenue, Newport, R.I.	June 2, 1886.
MCKEE, SAMUEL BINGHAM	Canadian Pacific R'y Offices, Montreal, Canada	June 2, 1886.
SAWYER, CHARLES HENRY	Assistant Engineer Union Pacific R'y, Pilot, Nebraska	June 2, 1886.
SCHAEFFER, JOHN STEWART	Engineer and Superintendent Newark's Improved Sewerage, Heath Building, Newark, N. J.	June 2, 1886.
SCOTT, ADDISON MOFFAT	U. S. Assistant Engineer, Charleston, West Va	June 2, 1886.
WALLACE, JOHN FINDLEY	Master of Transportation and Engineer of Construction Eastern and Illinois Divisions Central Iowa R'y, Keithsburg, Ill	June 2, 1886.

ASSOCIATE. Date of Election.

WOODWARD, CALVIN MILTON...Thayer Professor of Applied Mechanics and Higher Mathematics, Dean of Polytechnic School, Washington University, St. Louis, Mo.....June 2, 1886.

JUNIORS.

BARNEY, SAMUEL EBEN, JR....P. O. Box 602, New Haven, Conn. June 2, 1886.

BONNETT, CHARLES PIERRE....421 Westminster avenue, Elizabeth, N. J.....June 2, 1886.

GOLDSMITH, NATHANIEL OLIVER. Engineer The Weir Frog Co., Glendale, Ohio.....June 2, 1886.

MILLS, CHARLES MALON.....(Care Union Bridge Co.), 18 Broadway, New York City.....June 2, 1886.

SEAMAN, HENRY BOWMAN.....Assistant Engineer Kings County Elevated R'y, 26 Court Street, Brooklyn, N. Y.....June 2, 1886.

VAN ZILE, HARRY LEE.....Troy and Albany Bridge and Ironworks, Troy, N. Y.....Jan. 6, 1886.

CHANGES AND CORRECTIONS.

MEMBERS.

ABERT, S. THAYER.....U. S. Agent, 810 Nineteenth street, N. W., Washington, D. C.

ALLEN, JAMES P.....9 Bull street, Charleston, S. C.

ATWOOD, WILLIAM H.....Division Engineer Colorado Midland R'y, Colorado Springs, Colo.

APPLETON, THOMAS.....(Care Chief Engineer Chicago, St. Paul and Milwaukee R'y), Milwaukee, Wis.

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BARNARD, AUGUSTUS P.....Sheffield, Berkshire Co., Mass.

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BELL, ANDREW.....Almonte, Ont., Canada.

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DAVIS, CHESTER B.....Rooms 75 and 76, Calumet Building, Chicago, Ill.

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GELLETTE, WILLIAM D.....(Care Chief Engineer Southern Pacific Co.), corner Fourth and Townsend streets, San Francisco, Cal.
GILLESPIE, JOSHUA L.....Box 2396, St. Paul, Minn.
HARRIS, WILLIAM P.....General Superintendent St. Joseph and St. Louis R. R., St. Joseph, Mo.
HARROD, BENJAMIN M.....Cotton Exchange Building, New Orleans, La.
HAVEN, WILLIAM A.....P. O. box 770, Helena, Montana.
HAYES, R. S.....(Care John S. Barnes), 18 Wall street, New York City.
HENTHORN, JOHN T.....173 Westminster street, Providence, R. I.
HERING, RUDOLPH.....Chief Engineer Drainage and Water Supply Commission, City Hall, Chicago, Ill.
HOWE, MILTON G.....Receiver Houston, East and West Texas R. R., Houston, Texas.
KATTÉ, WALTER.....Chief Engineer New York Central and Hudson River R. R., Grand Central Depot, New York City.
KILLEBREW, SAMUEL.....Assistant Engineer Mexican International R.R., Eagle Pass, Texas.
KINNEY, EDWARD C.....Assistant to Chief Engineer Union Pacific R'y, Omaha, Neb.
KITTREDGE, GEORGE W.....Engineer Maintenance of Way Jeffersonville, Madison and Indianapolis R. R., Columbus, Ind.
LAFON, THOMAS.....Engineer's Office Burlington and Missouri River R.R, Lincoln, Neb.
LATHAM, HARRY H.....Chief Engineer Utah and Wyoming R.R., Montauk Block, Chicago, Ill.
LUDLOW, WILLIAM.....Bvt. Lt.-Col. U. S. A., Engineer Commissioner District Columbia, Washington, D. C.
LUCIUS, ALBERT.....Chief Engineer Brooklyn, Bath and West End R.R., 297 Tenth st., South Brooklyn, N. Y.
MACLAY, WILLIAM W.....Superintendent Department of Docks office, foot Duane st., North River, New York City.
MAN, ALBON P., JR.....Ocala, Florida.
MAXWELL, JAMES R.....Division Engineer Union Pacific R'y, Butte, Montana.
MCALPINE, WILLIAM J.....Cor. Franklin and Pendleton aves, New Brighton, Richmond Co., N. Y.
MCCLINTOCK, WILLIAM H.....Resident Engineer Atlanta and West Point R.R., Western R'y of Alabama, and Cincinnati, Selma and Mobile R'y, Montgomery, Ala.
MCKEOWN, THOMAS.....37 City road, London, E. C., England.
MORRIS, ROBERT C.....Chief Engineer Nashville, Chatanooga and St. Louis R. R., Nashville, Tenn.
NICHOLS, AURIN B.....Rathmell, Pa.

PARET, MILNOR P.....Division Engineer Cincinnati and Richmond R.R., Oakley, Ohio.

PETERSON, PETER A.....Engineer Eastern Ontario and Quebec Division Canadian Pacific R'y, Chief Engineer St. Lawrence Bridge, Montreal, Canada.

RICHARDS, CHARLES B.....Professor Mechanical Engineering Sheffield Scientific School, Yale College, New Haven, Conn.

ROWE, SAMUEL M.....Resident Engineer Atchison, Topeka and Santa Fé R'y, Topeka, Kansas.

SCOTT, ARTHUR H.....First Assistant City Engineer, Milwaukee, Wis.

SORZANO, JULIO F.....33 Broadway, New York City.

THACKRAY, GEORGE E.....Youngstown Steel Co., Youngstown, Ohio.

THOMAS, JOSEPH R.....138 East 79th st., New York City.

TOWLE, STEVENSON.....115 Broadway, New York City.

VAN SANT, ROBERT L.....Chief Engineer St. Louis, Arkansas and Texas R'y, Texarkana, Texas.

WADDELL, JOHN A. L.....Phœnix Bridge Co., Phœnixville, Pa.

ASSOCIATES.

CARD, JOSEPH P.....President Chicago Tie Preserving Co., Chicago, Ill.

HENDRIE, JOHN S.....Railway Contractor, Hamilton, Ontario, Canada.

PUTNAM, JOSEPH W.....Drawer 253, New Orleans, La.

JUNIORS.

BARLOW, JOHN Q.....Assistant Engineer Northern Pacific R. R., Ellensburg, Wash.

FRANCIS, GEORGE B.....Assistant Engineer New York Central and Hudson River R. R., Depot Building, Rochester, N. Y.

FREEMAN, JOHN R.....31 Milk st., Boston, Mass.

KELLOGG, NORMAN B.....Division Roadmaster Southern Pacific Co., West Oakland, Cal.

MARVIN, CHARLES E.....Assistant Engineer Louisville and Nashville Division L. and N. R. R., Evansville, Ind.

ROSENWEIG, ALFRED.....Calle Cadena 3, Mexico, Mexico, *via* El Paso, Texas.

SANFORD, DAVID C.....Field Engineer Conn. Shell Fishery Commission, Box 1512, New Haven, Conn.

SMITH, MAXWELL.....Assistant Engineer Chicago, Milwaukee and St. Paul R'y, Milwaukee, Wis.

FELLOWS.

GILMAN, CHARLES C.....President The International Terra-Cotta Lumber Co., 115 Dearborn st., Chicago, Ill.

GURNEE, WALTER S.....7 Nassau st., New York City.

CONTRIBUTIONS TO THE BUILDING FUND.

By a resolution of the Board of Direction, all contributions to the Building Fund are to be acknowledged, from time to time by printing lists of the same in the monthly Proceedings of the Society, and in addition to this the names of all those who may subscribe $100 or more are to be regularly enrolled and published in future lists of the Society under the head of Subscribers to the Building Fund, and they will be entitled to receive one copy of the monthly publications, comprising all papers and transactions of the Society, regularly for life, for each $100 subscribed by them; such copies to be in addition to those which they may be already entitled to if they are Members or Fellows.

The following contribution up to this time is acknowledged:

William H. Paine..... $100 00

American Society of Civil Engineers.

PROCEEDINGS.

Vol. XII.—August, 1886.

[No meetings of the Society have been held during July and August except the meeting during the Convention, the report of which has been published in Proceedings for July.]

ADDITIONS TO

LIBRARY AND MUSEUM.

From American Institute of Mining Engineers, Dr. R. W. Raymond, Secretary, New York City:

The Estimation of Manganese in Iron and Steel by the Color Method. Alfred E. Hunt.
Mexican Weights and Measures. E. Richard Chism.
A Sectional Slag and Matte-Pot. Richard H. Terhune.
Specific Gravity of Low-Callow Steel. F. Lynwood Garrison.
The Action of Dilute Acids on Certain Varieties of Fused Sulphide of Iron. Edward Hart.
Notes on some Chinese Coals. John C. F. Randolph.
Sectional Hanging-Pipe Hot-Blast Oven. Arthur F. Wendt.
The Economic Geology of the Bristol and Bigstone Gap Section of Tennessee and Virginia. C. R. Boyd.
The Copper Ores of the South-West. Arthur F. Wendt.
A Rapid Method for the Determination of Phosphorus. F. A. Emmerton.
Note on the New Chemical Laboratory of the Missouri School of Mines. Prof. Charles E. Wait.
The Iron Ores and Coals of Alabama, Georgia and Tennessee. John B. Porter.
Notes of Mining in Oaxaca. W. A. Hooker.
Notes on the Geology of the Tilly Foster Ore Body, Putnam County, N. Y.
Proceedings of the Forty-fifth Meeting, Bethlehem, Pa., May, 1886.
Calorimetric Estimation of Manganese in Steel. Byron W. Cheever.
List of Officers, Members, Rules, etc., June, 1886.
The Antiolinal Theory of National Gas. H. M. Chance.
The Clapp-Griffiths Converter—Later Practice and Commercial Results. J. P. Witherow.
The Microscopic Structure of Car-Wheel Iron. F. Lynwood Garrison.
Discussion of Kent on Failures of Steel Boiler-Plates. Prof. T. Egleston.
The Effect of Caustic Lime in the Lixiviation of Silver Ores. C. A. Stetefeldt.
Soft Steel for Boiler-Plates. Alfred E. Hunt.
The Product of the Hibernia Iron Mine, N. J. J. Wesley Pullman.
The Cornwall Iron-Ore Mines, Lebanon Co., Pa. E. V. d'Invilliers.
Operation of Warwick Furnace, Pennsylvania, from August 27th, 1880, to September 1st, 1885. John Birkenbine.
Discussion of Blake on Utah Iron-Ore Deposits. G. W. Maynard.
Notes on the Stamp Mills and Chlorination Works of the Plymouth Consolidated Gold Mining Company, Amador County, Cal. George W. Small.

From American Iron and Steel Association, James M. Swank, Secretary, Philadelphia, Pa.:

Annual Statistical Report for 1885.

From Lewis S. Alter, Cor. Secy. Asso-

ciation of County Surveyors and Civil Engineers of Indiana, Remington:

Proceedings of the Association for January 19th and 20th, 1886.

From James Angline & Co., Washington, D. C.:

Catalogue of the More Valuable Publications of the U, S. Government, 1885.

From Rear-Admiral Daniel Ammen, U. S. N., Washington, D. C.:

The Errors and Fallacies of the Inter-Oceanic Transit Question.

From George H. Benzenberg, Milwaukee, Wis.:

Annual Report of the Board of Public Works and City Engineer of the City of Milwaukee for the year ending December 31st, 1885.

From Board of Railroad Commissioners of the State of New York:

Third Annual Report, Vols. I and II, for 1885.

From Henry R. Bradbury, New York City:

Report of Works Executed by the Commissioners of Sewers of the City of London, during the year 1884–85. By Wm. Haywood.

From W. H. Breithaupt, Kansas City, Mo.:

Photograph of Hannibal and St. Joseph Bridge, Kansas City, Mo., May 12th, 1886.

From Fred. Brooks, Boston, Mass.:

Report of Committee of Boston Society of Civil Engineers on Weights and Measures. (Several Copies.)

From Bureau of Navigation, Washington, D. C.:

Pilot Chart for the North Atlantic Ocean for the Months of May, June, July and August, 1886.

The Naval Brigade and Operations Ashore.

From M. J. Butler, Napanee, Canada:

Proceedings of the Associations of Provincial Land Surveyors of Ontario, February 23d, 24th and 25th, 1886.

From B. A. Colonna, Washington, D. C.:

Testimony before the Joint Commission to Consider the Present Organization of the Surveys.

From J. James R. Croes, New York City:

Framed Photograph of the Harlem River Bridge of the Suburban Rapid Transit Co.

Contract for the Construction of the Iron Structures, Piers and Foundations of the Third Avenue Line of the Suburban Rapid Transit Co.

Specifications for Cast-Iron Bases and Wheel-Guards for the same.

From A. S. Crowninshield, Naval Advisory Board, Washington, D. C.:

Description of Route, Estimated Cost and Business of the Nicaragua Canal. (*Copies for distribution.*)

From Denver Chamber of Commerce and Board of Trade, Denver, Colo.:

Reports on the Feasibility of Establishing Slaughter Canning and Packing-Houses, with Manufactures incident thereto, in the City of Denver for the year 1885.

Annual Report of the Commissioner of Indian Affairs for the year 1884.

Report on the Leather and Shoe Industries, December, 1885.

Report of the Superintendent of Indian Schools for the year 1884.

Eleventh Annual Report of the Board of Education of District No. 1, Arapahoe County, Colo., September 1, 1885.

Twenty-eighth Annual Report of the Trade and Commerce of Milwaukee for the year ending December 31st, 1885.

The Chamber of Commerce Journal, Volume V, No. 47, January 5th. 1886.

The American Brewers' Gazette, May, 1886.

The Reporter, April, 1886.

Colorado Horticultural Report for the year 1885.

Second and Third Annual Reports of the Denver Chamber of Commerce and Board of Trade, Denver, Colo., for the years ended December 31st, 1884 and 1885.

Reports on the Commerce, Manufactures of their Consular Districts, etc., April, 1886.

Address by Hon. N. P. Hill on Silver Coinage.

Speech of Hon. G. G. Symes, of Colorado, April 7, 1886, on Silver Coinage.

From Denver Society of Civil Engineers, Edmund S. Davis, Secretary, Denver, Colo.:

Some Answers to Questions likely to be asked by the Members of the American Society of Civil Engineers during their visit to Denver on the occasion of their Annual Convention, July 2d, 1886.

From Edward B. Dorsey, New York City:

Seventeenth to Twenty-second Annual Report of the Chicago, Milwaukee and St. Paul Railway Company.

Report of Mr, Russell Aitken on Vyrnwy Masonry Dam.

Report of Mr. Arthur Hill Holme, on the Vyrnwy Water-works.

Report of Major-General Sir Andrew Clark on the Vyrnwy Masonry Dam.

Report of the Directors of the Chicago, Burlington and Quincy Railroad Company for the years 1860 to 1885, lacking 1861, 1868, 1875 and 1880.

The Tenth to Fourteenth Annual Reports of the Board of Directors of the New York, New Haven and Hartford Railroad Co.

The South Mountain Water Co.'s Proposition to the Councils of the City of Philadelphia to leave the Water-works and Construct a new system of Water Supply for the City of Philadelphia.

Thirty-ninth Annual Report of the Board of Directors of the Pennsylvania Railroad Company to the Stockholders. Presented at the meeting held March 9th, 1886.

Register of the Commissioned and Warrant Officers of the Navy of the United States, including Offiers of the Marine Corps, to January 1st, 1886.

Report of the Commissioner of Public Works of New York City to the Aqueduct Commissioners, Supplementary to his Report of August 8th, 1883.

Report of Isaac Newton Chief Engineer of Croton Aqueduct, on Plans proposed for Storing and Conveying an Additional Water Supply to the City. Opinions of the Con-

sulting Engineers, Tables of Rainfall, Maps showing Drainage Area and Aqueduct Lines.

From W. F. Durfee, New York City:
The Mitis Process of Producing Wrought-Iron and Steel Castings.

From Dyckerhoff & Sohne, Amoeneberg, Germany:
Minutes of the Ninth General Meeting of the German Cement Manufacturers, February, 1886.

From N. W. Ellis, Manchester, N. H.
La Lumière Electrique son histoire, sa production et son emploi. Par Em-Alglave et J. Boulard.

From Engineers' Society of Western Pennsylvania, Pittsburgh, Pa.
Eads' Proposed Ship Railway across the Isthmus of Tehuantepec.
Long Distance Transportation of Natural Gas.
Pittsburgh Testing Laboratory,
Specifications for Material and Workmanship of Structures of Iron and Steel. Alfred E. Hunt.

From John M. Goodwin, Sharpsville, Pa.:
Profiles Boston to Hudson River, three routes:
1. *Via* Troy and Greenfield, "Hoosac Tunnel" Route.
2. *Via* Springfield and Pittsficid, Boston and Albany Route.
3. *Via* Willimantic and Hartford.

From George S. Greene, Jr., New York City:
Address to the Public on the advisability of purchasing Belle Isle for a Park, Waterworks, and Basis for a Tunnel.
Report of the Medical Commission of the City of Boston upon the Sanitary Qualities of the Sudbury, Mystic, Shaushine and Charles River Waters.
Fourth and Fifth Report upon the Improvement of the South Pass of the Mississippi River, showing condition of the works on August 17, 1876, and November 18, 1876.
Report on the Jetty System as applied to the Channel of Entrance to Cumberland Sound. Gen. Q. A. Gillmore.
Eighth Annual Report of the Board of Harbor Commissioners. January, 1874
Report on the proposed Chesapeake Bay and Potomac River Tide Water Canal from Washington to Annapolis. S. H. Sweet.
Prospectus of the New York, Housatonic and Northern Railroad Company. 1864
Certificate of Incorporation, By-Laws and Prospectus of the Earth-Boring Machine Co. 1868.
Report of the Water Commissioners of the City of Albany, N. Y., for the years 1864 to 1867; also Review of the Water Commissioners' Report for 1856.
Statements of H. Haupt on the Troy and Greenfield Railroad, Cambridge, Mass., January 31, 1862.
Physics and Hydraulics of the Mississippi River. St. Louis, February 19, 1876.
Annual Report upon the Improvement of Rivers and Harbors in the States of New York (including the Removal of Obstructions at Hell Gate) and New Jersey.
Report on the Improvement of the South Pass of the Mississippi River.
R. A. Hill's Stop and Branch for Street Mains and Multiple Fire Plugs.
Design for a Bridge across the East River, New York, at Blackwell's Island.
Majority Report of the Committee on Water and Union of Mystic and Cochituate Water Boards.
Abstract of the Discussion upon a paper on American Iron Bridges, submitted by Zerah Colburn.
Proceedings of the Seventh Annual Convention of the American Institute of Architects, held in Chicago October 15th, 16th and 17th, 1873.
Report from the Engineers to the Metropolitan Commissoners of Sewers.
Reports, etc., of District Engineers of the working of Pipe Sewers.
Reports on the State of the Works of Drainage and Sewerage of Croydon.
Reports of Survey as relating to House Drainage and Water Supply.
Van Nostrand's Eclectic Engineering Magazine, Vols. I, II and III bound: volumes IV to XV unbound; January to April, 1877, of Vol. XVI.

From S. S. Guthrie, Buffalo, N. Y.:
Address before the Merchants' Exchange of Buffalo, N.Y., on the Great Northern Transportation Route between the Atlantic and Pacific. S. S. Guthrie.

From William Hamilton, Toronto, Canada:
Annual Report of the Toronto Water-works for the year ending 31st December, 1885.

From Charles A. Hinckeldeyn, Technichal Attaché, Imperial German Legation, New York City:
Die Bestimmung von Normal Profilen fur die Elbe von der Sarhsisch-preussischen Grenze bis Geesthacht. Mit Atlas.

From John R. Hudson:
Tables for Calculating the Cubic Contents of Excavations and Embankments by an Improved Method of Diagonal and Side Triangles.

From Institution of Civil Engineers, James Forrest, Secretary, London:
On the Antiseptic Treatment of Timber. Samuel Bagster Boulton. (With an abstract of the discussion upon the paper.)
List of Members of the Institution of Civil Engineers, 3d June, 1886.
On the Explosion of Gaseous Mixtures. Dugald Clark. With an abstract of the discussion upon the paper.
On the Wear of Steel Rails. Harry Footner.
Sewer Ventilation. George R. Strachan.
Recent Researches in Friction. John Goodman.
The Economical Construction of Railways. Robert Gordon, James Robert Morse, Granville Carlyle Cunningham. With an abstract of the discussion upon the paper.
English and American Railroads Compared. Edward Bates Dorsey.
Experiments on the Discharge of Water of Different Temperatures. John George Mair.
On Rail Joints and Steel Rails. Christer Peter Sandberg.

On the Rate of Hardening of Cement and Cement-Mortars. Prof. Wm. Cawthorne Unioin.
The Strength of Steel and Wrought-Iron Girders. Abstract from a Report to the Dutch Minister of Public Works.
The Granada Earthquake of 25th December, 1884. Edward J. T. Manly.
Water Purification: its Bi-Logical and Chemical Basis. Percy F. Frankland. With an abstract of the discussion upon the paper.
The River Seine. Leveson Francis Vernon Harcourt. With an abstract of the discussion upon the paper.
On Gas Producers. Frederick John Rowan. With an abstract of the discussion upon the paper.
The Injurious Effect of a Blue Heat on Steel and Iron, C. E. Stromyer. With an abstract of the discussion upon the paper.
Abstracts of Papers in Foreign Transactions and Periodicals.
Proceedings. Vols. LXXXIV and LXXXV, 1885–86, Parts II and III.

From Hon. John J. Ingalls, Washinging. D. C.:
Speech of Hon. John J. Ingalls, of Kansas, on Relations between the Senate and Executive Departments.

From Wm. A. Jefferis, New York City:
The Naturalist's Leisure Hour and Monthly Bulletin for January, February, March and April, 1886.

From John Kennedy, Montreal, Canada:
Annual Report of the Harbor Commissioners of Montreal for the year 1885.

From Louis H. Knapp, Buffalo, N. Y.:
Seventeenth Annual Report, Buffalo City Water-works. 1885.

From J. F. Le Baron, Jacksonville, Fla.:
Map of the City of Jacksonville and Suburbs, Duval County, Florida.
An Article on the Hydraulics of the Okeechobee Region, Florida.

From Louis Lesage, Montreal, Canada.
Annual Report of the Superintendent of the Montreal Water-works for the year ending 31st December, 1885.

From Wm. J. McAlpine, Bay Ridge, N. Y.:
Ten Sheets, showing Plans of Harlem Bridge.
Form of Proposals.
Specifications for its Construction. 1886.
Memorandum of Verbal Information given to various Persons who have asked Questions in regard to the Plans, Specifications, etc.

From John MacLeod, Louisville, Ky.:
Two Photographs of the Kentucky and Indiana Bridge.

From Capt. O. E. Michaelis, U. S. A., West Troy, N. Y.:
The Application of Electricity to the Development of Markmanship.

From H. C. V. Moller, Copenhagen, Denmark:
Beskrivelse af det i Nordamerika anvendte Materiel til Uddylring. I. Flode rog Havne.

From George S. Morison, New York City:
Specifications for Superstructure for Bridge across the Missouri River at Rulo, Nebraska.
Tenth Census of the United States. Volumes I to XIV, lacking Volume XII.
Compendium of the Tenth Census. Parts I and II.

From Robert C. Morris, Nashville, Tenn.:
Annual Report of the Nashville, Chattanooga and St. Louis Railway. July 1, 1885.

From Gen. John Newton, Chief of Engineers U. S. A., Washington, D. C.:
Statement Showing Rank, Duties and Address of the Officers of the Corps of Engineers.
Report Relative to the Condition of the Aqueduct Bridge.
Report on the River and Harbor Bill for the Improvement of the Navigation of the Mississippi River.
Report Calling for Information Relative to the Erection of Fish-Ways at the Great Falls of the Potomac.
Report for the Construction of a Bridge Across the Potomac River.
Advertisements, Specifications and Proposals for Improvement of Rivers Emptying into San Pablo and Sinsun Bays.
For Improvement of Harbor Grand Haven, Mich.
For Building One Steam Launch for the Harbor of Refuge, Lake Huron.
For Office Supplies U. S. Engineer's Office, Cincinnati, Ohio.
For a New Tin Roof for the Executive Mansion.
For Dredging at Five Mile Bar, above Peltry's Island.
For Dredging Portland Harbor, Maine.
For Constructing Dike between Hog and Maiden Islands.
For a Concrete Block for Sandy Bay, Mass.
For Repairing Snag-boat.
For Iron and Steel Dam at Beattyville, Ky.
For Timber and Piles for Dam at Beattyville, Ky.
For Removal and Landing of Wreck of Schooner "Waldemar," now lying in Belfast Harbor, Me.
For Irons for Gates of Lock No. 6, Great Kannawha River, W. Va.
For Furnishing and Placing Stone in the Gap at the Delaware Breakwater.
For the Removal of the Wrecks of the Brig "Clio," and Steamer "North Heath."
For Dredging Racine Harbor, Wis.
For Hire of Dredge for Improving Port Chester Harbor, N. Y.
For Wrought-Iron Spikes Dam at Beattyville, Ky.
For the Upper Works, Cabin, etc., of a Steel and Iron Snag-boat.
Report relative to Appropriation for Breakwater at Port Orford, Oregon.
Report submitting an Additional Estimate for Repairs of Works at Olcott Harbor, N. Y., rendered necessary by damage caused by recent storms.
Report relative to the condition of the Government Works near Battery Island Light.
Report relative to the Construction of a Harbor of Refuge at Sandy Bay, Mass.
Report asking an Appropriation for Continuing Examinations and Surveys at South Pass, Mississippi River.

Report showing the Maintenance of the Channel of the Mississippi River.
Report of Major W. A. Jones on River Improvements in Oregon and Washington Territory.
An Estimate from the Secretary of War for the purchase of additional ground at Fort Hamilton, New York Harbor.
Specifications and Proposals as follows:
Harbor Improvement Muskegon, Mich.
Machinery for Tow-boat, for Louisville and Portland Canal.
Improvement of San Francisco Harbor, California.
Tow-boat for Louisville and Portland Canal.
Relating to Dredging in Annapolis Harbor, Maryland.
Removal of the Wreck of the Steamer "Dictator," now lying in the harbor at Tampa, Fla.
Stationery Supplies.
Rip-rap Stone, Ohio River.
Repairing Sand-Catch at Plum Island, Newburyport Harbor, Mass.
Building two Scows with Hoisters.
Coal for Louisville and Portland Canal, and Offices in Louisville, Ky.
Harbor Improvement, White River, Mich.
" " Manistee, "
" " Frankfort, "
Supplies and Material for Bridges.
Removal of Wreck off Cape Henlopen, Del.
Chains for Dam No 6, Great Kanawha River, W. Va.
Irons for Weir, etc., of Dam No. 6, Great Kanawha River, W. Va.
For Rip-rap Stone Dam at Beattyville, Ky.
For Improvement Harbor Saint Joseph, Mich.

From New York State Board of Health, Albany, N. Y.:
Monthly Bulletin, April, May, June and July. 1886.
Fifth Annual Report for 1885.

From New York Meteorological Observatory, Dr. Daniel Draper, Director, Central Park, New York City:
Abstracts of Registers from Self-Recording Instruments, January, February, March, April, May and June, 1886.

From Edward P. North, New York City:
Report upon Paving, etc., Certain Streets and Roads in the Borough of Birmingham, England, February 17, 1874.
Report on the Application of Science and Art to Street Paving and Street Cleansing of the Metropolis.
Communication from Board of Health relative to the Condition of the New Aqueduct, New York.
Fifth Annual Report of the State Board of Health of New York for 1885.
Record of Correspondence and Interviews between Jay Gould and the Officers of the Knights of Labor in reference to the late strike on the Missouri Pacific Railway Company.

From Albert F. Noyes, West Newton, Mass.:
Transactions of the New England Water-Works Association during the year 1885.

From Frank C. Osborn, Pittsburgh, Pa.:
Osborn's Tables of Moments of Inertia and Squares of Radii of Gyration.

From Charles Paine, Pittsburgh, Pa.:
Philadelphia Company's Yellow Book on Natural Gas.
Annual Report of the Philadelphia Company for 1885-86.

From Hon. Charles F. Peck, Commissioner, Albany, N. Y.:
Third Annual Report of the Bureau of Statistics of Labor of the State of New York for the year 1885.

From Franklin C. Prindle, East Orange, N. J.:
A Descriptive Catalogue of the Government Publications of the United States, September 5, 1774-March 4, 1881.

From Rand Drill Company, New York City;
One Instantaneous Photograph of Hell Gate, taken during Explosion of October 10, 1885.

From Railway Purchasing Agent Company, Chicago, Ill.:
The Official Railway List, 1886.

From Henry B. Richardson, New Orleans, La.:
Report of the Board of State Engineers of the State of Louisiana from April 20, 1884, to April 20, 1886.

From Frederic H. Robinson, Wilmington, Del.:
Fifteenth Annual Report of the Chief Engineer of the City to the Council for the year 1885.

From Andrew Rosewater, Omaha, Nebraska:
Annual Report of the City Engineer of the City of Omaha, April 1, 1885, to April 1, 1886.

From Collingwood Schreiber, Ottawa, Canada;
Profile of the Canadian Pacific Railway west of Lake Superior, in comparison with the Northern, Union and Central Pacific Railways.
Railway Statistics of Canada, 1884-85.

From T. Guilford Smith, Buffalo, N. Y.:
Statistics of the Trade and Commerce of Buffalo, 1885.

From Hamilton Smith, Jr., London, England:
Hydraulics: The Flow of Water through Orifices, over Weirs, and through Open Conduits and Pipes. Hamilton Smith, Jr. Vol. I, Text. Vol. II, Plates. London and New York, 1886.

From Smithsonian Institution, Washington, D. C.:
Annual Report of the Board of Regents of the Smithsonian Institution for the year 1884.

From Society of Engineers, Charles Julian Light, Secretary, London, England:
Transactions for 1885.

From A. J. Stevens, Gen. Master Mechanic Southern Pacific Co., Laer, Cal.:

Blue Prints of two heavy Locomotives now in use on Southern Pacific Company. Pacific System.

From Prof. George F. Swain, Boston, Mass.:

Tenth Census Report for 1886. Vol. XVI, Water Power, Part I.

From Prof. A. N. Talbot, Champaign, Ill.:

Report of the First Annual Meeting of the Illinois Society of Engineers and Surveyors, held at Champaign, Ill., Feb. 10th, 11th and 12th, 1886.

From Benjamin Thompson, Urbana, Ohio:

Seventh Annual Report of the Ohio Society of Surveyors and Civil Engineers, 1886.

From John C. Trautwine, Philadelphia, Pa.:

The Civil Engineer's Pocket Book for 1886.

The Field Practice of Laying out Circular Curves for Railroads.

From Union Bridge Company, New York City:

Four Photographs of the Kentucky and Indiana Bridge.

From United States Geological Survey, Washington, D. C.:

Monographs of the United States Geological Survey. Vol. IX.

Bulletin of the U. S. Geological Survey. Nos. 24, 25 and 26.

From United States Naval Observatory, Washington, D. C.:

Astronomical and Meteorological Observations made during the year 1882 at the United States Naval Observatory.

Papers on Squadrons of Evolutions and the Recent Development of Naval Material, June, 1886.

From Frederick W. Vaughan, Louisville, Ky.:

Louisville and Nashville Railroad Company. Sheets showing Performance of Engines and Cost per Mile Run for the Months of April to December, 1885, and from January to March, 1886.

Annual Report of the Louisville and Nashville Railroad Company for 1875, 1878–79, and 1881 to 1885.

From Lieut. Anthony W. Vogdes, U. S. A., Governor's Island, N. Y.:

Notes on the Distribution of Iron Ores in the United States.

Ordnance Notes, as follows:

Geometrical Solution of the Problem of the Trajectory of a Projectile in Vacuo. Prof. A. G. Greenhill.

Mars-la-Tour and Gravelotte. Lieut. John Bigelow.

Fabrication of 8-inch Eureka Projectiles. Henry D. Borup.

Puddled *vs.* Cast-Steel as Metal for Gun Hoops. Lieut. Rogers Birnie.

The Eighty-Ton Steam Hammers of Creusot and St. Chamond. S. Crispin.

Krupp Experiments. Reports III and XLVII.

Field Artillery. Capt. D. T. A. De Sotomayor.

Paints and Lacquers for Artillery Material.

Practical Instructions in Gunnery.

Improved Capstan. Henry Metcalfe.

Target Practice—Information for Soldiers. Col. Guy V. Henry.

Machines for the Physical Tests of Metals. Lieut. W. M. Metcalfe.

Synopsis of the Principal Points in the Theory of the Probability of Fire. E. Jouffret.

The Hawaiian Islands and People. Capt. C. E. Dutton.

Stencil Outfit. D. W. Flagler.

Report on Transcontinental Railways 1883. Gen. O. M. Poe.

Strategical Value of the Inland Canal Navigation of the United States. First Lieut. Tasker H. Bliss.

Wild-Fowl and Punt Guns. Major W. McClintock.

The Trajectories, Time of Flight, Remaining Velocities and Striking Energies of Bullets Fired from Large Bow and Express Rifles. Major W. McClintock.

Comparative Table of Austrian, English, French, German, Italian, and Russian Field Guns. Major S. C. Pratt.

The Manufacture of Steel and Its Application to Military Purposes. Captain G. Mackinley.

Field Artillery Fire.

United States Life-Saving Service. D. A. Lyle.

Meteorological Investigations. Capt. O. E. Michaelis.

A Peculiar Phase of Metallic Behavior. Capt. O. E. Michaelis.

Electrical Units of Measurement. Sir William Thomson.

Electricity Applied to Explosive Purposes. Prof. F. A. Abel.

Statistics of Mines and Mining in the States and Territories West of the Rocky Mountains.

From Prof. J. A. L. Waddell, Phœnixville, Pa.:

An Address delivered by Prof. Waddell before the Members of Kogakukyokai, Tokio, Japan.

American *versus* English Methods of Bridge Designing. (Reprinted from the *Japan Mail.*)

From Edmund B. Weston, Providence, R. I.:

Rain-Gauge Investigations.

Bulletin of the New England Meteorological Society for March, 1886.

From George M. Wheeler, Capt of Engineers' U. S. Army, Washington, D. C.:

Report upon the Third International Geographical Congress and Exhibition at Venice, Italy, 1881.

From William H. Wiley, New York City:

The Pennsylvania Railroad: Its Organization, Construction and Management. James Dredge.

Resources of Southwest Virginia, showing the Mineral Deposits of Iron, Coal, Zinc, Copper and Lead. C. R. Boyd.

From other sources:

Report of the Hon. John Bigelow on the Inspection of the Panama Canal in February, 1886.

MEMOIRS OF DECEASED MEMBERS.

JAMES DEWEY BURR, M. Am. Soc. C. E.

DIED MAY 5TH, 1886.

James Dewey Burr was born at Allen, Allegany County, New York, August 31st, 1843. He lost his mother in early youth, and at the age of twelve he went to the home of a relative in Michigan. His father is still living.

Although not yet eighteen years of age, Mr. Burr enlisted in April, 1861, in the 4th Michigan Infantry, and was in the army three years. His health never recovered from the results of the exposure to which he was subjected during that period.

Entering the University of Michigan, he graduated as a Civil Engineer in 1871, and directly afterward entered the engineer service of the Flint and Pere Marquette Railway. He was next engaged upon the Cincinnati Southern Railway until March, 1877, when he was appointed Superintendent of Bridges and Buildings of the Atchison, Topeka and Santa Fé Railway. In June, 1878, he went to Colorado as Assistant Chief Engineer and Superintendent of Construction of the lines of the same road from La Junta, Colorado, to Las Vegas, New Mexico. This line passes over the Raton Mountains. After the construction of these lines, Mr. Burr did some work in New Mexico and Arizona, and then, resigning his connection with the railway, he formed a partnership with Mr. B. Lantry, at Topeka, Kansas, and engaged actively in railway construction and bridge-building. He has resided at Topeka continuously since that time. He was President of the First National Bank of that city.

Mr. Burr was a careful and thorough engineer, and an authority in bridge construction. He was deeply devoted to his profession, and took great interest in engineering works even after failing health prevented an active participation in them.

In October, 1877, Mr. Burr was married to Miss Jennie Van Fleet, of White Pigeon, Michigan, who, with a young son, survives him. Mr. Burr was greatly respected in the city where he resided. His life was characterized by integrity and energy. He had much equanimity of character, and his associations in business and social life were remarkably strong.

A paper written by Mr. Burr was presented at the Annual Convention of the American Society of Civil Engineers in June, 1879, and published in the Transactions for October of that year. The subject was the Construction of the Atchison, Topeka and Santa Fé Railroad over the Raton Mountains, and the performance of locomotives over its steep grades. The paper was ably written, excellently illustrated, and excited much interest.

Mr. Burr became a member of the American Society of Civil Engineers April 5th, 1876.

American Society of Civil Engineers.

PROCEEDINGS.

Vol. XII.—September, 1886.

MINUTES OF MEETINGS.

(Abstract of such as may be of general interest to members.)

OF THE SOCIETY.

September 1st, 1886.—The Society met at 20 o'clock, Vice-President Thomas F. Rowland in the chair; John Bogart, Secretary. Ballots were canvassed, and the following candidates declared elected. As Members: Josiah Ackerman Briggs, New York; Carl Waldemar Buchholz, New York; Francis Eave Butterfield, San Antonio, Texas; Alfred Epher Hunt, Pittsburgh, Pa.; Jones Mumford Jackson, Wynne, Ark.; Charles Leonard Rowland, Brooklyn, N. Y.; Thomas Fitch Rowland, Jr., Brooklyn, N. Y.; William Rumble, Bayonne, N. J.; Frank Woodward Skinner, Buffalo, N. Y.; William Johnston Sproule, Montreal, Canada; Thomas Mann Randolph Talcott, Mobile, Ala. As Juniors: Edward Lorenzo Abbott, New York; William Clinton Brown, New York; William Cushing Edes, Boston, Mass.; George Robertson Hooper, Montreal, Canada; Montgomery Waddell, New York.

The death on August 18th, 1886, of Mr. E. S. Chesbrough, Past President Am. Soc. C. E., was announced; also the death on June 8th, of Richard M. Hoe, M. Am. Soc. C. E.

A crayon portrait of Mr. James Laurie, First President of the American Society of Civil Engineers, presented by Mr. William E. Worthen, M. Am. Soc. C. E., was exhibited.

The report of the Committee on the Compressive Strength of Cements and the Compression of Cements and Settlement of Masonry was read by the Chairman, Mr. F. Collingwood, M. Am. Soc. C. E., and discussed by Messrs. Dorsey, Emery, Flagg, Prindle and Collingwood.

Some remarks on Earthquakes were made by Messrs. R. L. Harris, Collingwood, Dorsey, and Emery.

SEPTEMBER 15TH, 1886.—The Society met at 20 o'clock, Vice-President Rowland in the chair; John Bogart, Secretary. A paper by Mr. John W. Hill, M. Am. Soc. C. E., on "A Masonry Dam," was read.

Some experiences of the recent earthquake at Charleston, S. C., were given by Mr. H. A. Duc, Jr., who was in that city at the time.

OF THE BOARD OF DIRECTION.

JUNE 9TH, 1886.—Applications were considered. The arrangements for the Convention were discussed. It was ordered, under the provisions of the By-Laws, that the meetings of the Society be suspended during July and August, except the business meeting to be held during the Convention. The resignation of Mr. William Metcalf as Chairman of Committee to Consider Changes in Organization was presented. Appropriations were made.

AUGUST 11TH, 1886.—Applications were considered. The following members were appointed a Board of Censors to award the Norman Medal: Messrs. Thomas C. Meyer, Frederic Graff and Charles E. Greene. The following members were appointed to be, with the Secretary, the Committee to award the Rowland Prize: Messrs. F. De Funiak and Frederick H. Smith.

The resolution adopted at the recent Convention in reference to changes in organization was considered, and the Secretary was directed to issue the resolution in circular form. Appropriations were made.

SEPTEMBER 1ST, 1886.—Applications were considered and appropriations made.

THE ROWLAND PRIZE.

CODE OF RULES FOR ITS AWARD.

Not more than one prize shall be awarded each year for papers presented during the year. The year shall terminate on the first day of August, and the award shall be announced at the annual meeting in January.

The prize shall consist of fifty dollars in cash.

The award shall be made by a committee consisting of the Secretary and two Members of the Society, to be appointed by the Board of Direction.

The prize shall be awarded to such paper as the committee deem most worthy of such recognition, the preference being given to papers describing in detail accomplished works of construction, their cost and manner of execution, and the errors in design and execution.

THE NORMAN MEDAL.

CODE OF RULES FOR ITS AWARD.

I.—Competition for the Norman Medal of the American Society of Civil Engineers shall be restricted to Members of the Society.

II.—There shall be one gold medal, and only one, struck for each and every fiscal year of the Society, and awarded as hereinafter provided. The dies therefor shall be with the Superintendent of the United States Mint at Philadelphia, in trust exclusively for the above purpose. Such medal shall be of a cost equal to the annual interest received upon $1 000 of the Consolidated Stock of the City of New York, Certificate No. 179, of the additional new Croton Aqueduct Stock of the City of New York, authorized by an Act of the Legislature of the State of New York, Chap. 230, passed April 15th, 1870, dated November 17th, 1873, now held in trust by the Treasurer of this Society, and so held solely for this purpose, and shall be executed upon his order.

III.—All original papers presented to the Society by Members of any class, during the year for which the medal is awarded, shall be open to the award, provided that such papers shall not have been previously contributed in whole or in part to any other association, nor have appeared in print prior to their publication by the Society, nor have been presented to the Society in any previous year.

IV.—The Board of Censors to award the medal shall consist of three Members of the Society, to be designated by the Board of Direction. The Secretary of the Society shall act as Secretary to the Board of Censors.

V.—The medal shall be awarded to such paper as the said Board shall judge to be worthy of special commendation for its merits as a contribution to engineering science, not merely relatively as compared with others presented during the same year, but as exhibiting the science, talent or industry displayed in the consideration of the subject treated of, and for the good which may be expected to result from the discussion and the inquiry.

VI.—In case no paper presented during the year shall be deemed of sufficient value to receive an award, the amount of the interest of the fund for that year shall be expended by the Board of Direction in the purchase of books, to be offered as a premium for the second best paper in the next year in which more than one paper of sufficient value may be presented.

VII.—The medal year shall terminate on the first day of August, and the award shall be announced at the annual meeting.

VIII.—The Treasurer of this Society shall cause the medal to be prepared and delivered to, or deposited to the order of, the successful competitor, within two months after the annual meeting at which the same shall have been awarded.

LIST OF MEMBERS.

ADDITIONS.

MEMBERS. Date of Election.

BRIGGS, JOSIAH ACKERMAN...Fordham, New York City.....Sept. 1, 1886.

BUCHHOLZ, CARL WALDEMAR.Engineer Bridges and Buildings New York, Lake Erie and Western R. R., 187 West street, New York City.....Sept. 1, 1886.

JACKSON, JONES MUMFORD ...Assistant Engineer Missouri Pacific R. R., Wynne, Ark.....Sept. 1, 1886.

ROWLAND, CHARLES LEONARD.61 Morton street, Brooklyn, N. Y..Sept. 1, 1886.

ROWLAND, THOMAS FITCH, JR. Station G, Brooklyn, N. Y.....Sept. 1, 1886.

RUMBLE, WILLIAM.....Civil and Mechanical Engineer, Bayonne, N. J.....Sept. 1, 1886.

SKINNER, FRANK WOODWARD.1057 West avenue, Buffalo, N. Y....Sept. 1, 1886.

SPROULE, WILLIAM JOHNSTON, Assistant Engineer Montreal Harbor and Ship Channel Improvements, Montreal, Canada .....Sept. 1, 1886.

TALCOTT, THOMAS MANN RANDOLPH.....Superintendent Mobile and Ohio R. R., St. Louis, Mo.....Sept. 1, 1886.

JUNIORS.

ABBOTT, EDWARD LORENZO...(Care Sooysmith & Co.) 2 Nassau street, New York City.....Sept. 1, 1886.

BROWN, WILLIAM CLINTON...86 Liberty street, New York City...Sept. 1, 1886.

WADDELL, MONTGOMERY.....(Care J. A. L. Waddel), Phœnixville, Pa.....Sept. 1, 1886.

DEATHS.

CHESBROUGH, E. S.....Past President; elected Member June 17, 1868; died August 18, 1886.

HOE, RICHARD M..... Elected Member October 1, 1873; died June 8, 1886.

American Society of Civil Engineers.

PROCEEDINGS.

Vol. XII.—October, 1886.

MINUTES OF MEETINGS.

(Abstract of such as may be of general interest to members.)

OF THE SOCIETY.

October 6th, 1886.—The Society met at 20 o'clock, Vice-President Rowland in the chair; John Bogart, Secretary. Ballots were canvassed, and the following candidates declared elected as Members: Samuel George Artingstall, Chicago, Ill.; George Birdsall Cornell (elected Junior August 6, 1879), Brooklyn, N. Y.; Benjamin Lincoln Crosby, (elected Junior June 2, 1880), Rulo, Neb.; James Gustavus Dagron, Pittsburgh, Pa.; Stephenson Waters Fox (elected Junior July 7, 1880), St. Joseph, Mo.; Frederick William Doane Holbrook, Glendive, Mont.; George Anthony Lederle (elected Junior May 2, 1883), Omaha, Neb.; Leonor Fresnel Loree, Logansport, Ind.; Sampson Douglas Mason, St. Paul, Minn.; Robert John McClure, Denver, Colo.; James Henry Morley, St. Louis, Mo.; Thomas O'Neill Morris, Indianapolis, Ind.; Henry Cuyler Parsons, Albany, N. Y.; Alfred Petry, Covington, Ky.; Hugh Tudor Richards, Guaymas, Sonora, Mex.; Francis Morris Rutherford, Bordentown, N. J.; John Henderson Sample, Salina, Kas.; Julius William Schaub (elected Junior November 5, 1884), Montreal, Can.; Richard Willette Sherman, Utica, N. Y.; Miller Armstrong Smith, Brooklyn, N. Y.; John Frothingham Ward, New York City. As Associates: Frank W. Handy, Cincinnati, O.; Robert Cochran McKinney, Hamilton, O. As Juniors: Edward Marshall Boggs, Colorado Springs, Colo.; Francis Denis Hubert Lawlor, Burlington, Iowa.

It was announced that, under the rules, Messrs. T. C. Meyer, Frederic Graff and Charles E. Greene had been appointed the Board of Censors to award the Norman Medal; also that Messrs. Frederick De Funiak, Frederick H. Smith, and Secretary John Bogart, had been appointed the Committee to award the Rowland Prize.

A paper by Arthur D. Foote, M. Am. Soc. C. E., on A Water Meter for Irrigation was read and discussed.

A discussion by S. Whinery, M. Am. Soc. C. E., on Excessive Rainfall was read, and the subject was discussed.

October 20th, 1886.—The Society met at 20 o'clock, Vice-President Rowland in the chair; John Bogart, Secretary. The death on October 4th, 1886, of George H. Elliott, M. Am. Soc. C. E., was announced.

A paper by Charles E. Emery, M. Am. Soc. C. E., on a Clamp for Pulling Sheet Piling was read and discussed.

A paper by the same writer, on a Novel Application of the Polar Planimeter, presented at the last Convention, was discussed.

An interesting collection of exhibits illustrating phases of the recent earthquake at Charleston, S. C., sent by H. C. Duc, Jr., was presented, with an explanatory letter from that gentleman.

OF THE BOARD OF DIRECTION.

October 6th, 1886.—Applications were considered. Letters from a number of foreign engineers desiring to join the Society were presented, and the subject referred for consideration. Three replies to the circular in reference to proposed changes in the organization of the Society were considered. Appropriations were made.

MEMOIRS OF DECEASED MEMBERS.

EDWARD AUSTIN FLINT, M. Am. Soc. C. E.

Died January 23d, 1886.

Edward Austin Flint was born in Boston, January 30th, 1832, and died of pneumonia in Brookline, January 23d, 1886. He was the only son of Dr. John Flint, an eminent physician of Boston, and of a family that has given many notable men to the medical profession. After the usual five years' course in the Boston Public Latin School, he entered Harvard College in 1847, and graduated in 1851 with the degree of Bachelor of Arts, being the youngest member of his class. He then

entered "The Lawrence Scientific School," and left it in August, 1852, to enter upon the practical work of his chosen profession of civil engineering, beginning work as rodman of a construction party on the Ohio Central Railroad.

In August, 1853, he was called to the London and Port Stanly Railway in Canada, as Assistant Engineer, at first employed on surveys, and later as assistant on construction, and he remained on the road until its completion in January, 1857.

In the following April he was appointed Assistant Engineer on the Lansing and Francis Bay Railroad in Michigan.

Being appointed Resident Engineer of the Copiapo Railroad Company in August of the same year, he left for Chili to take charge of the extension of the road from Pabellon to Chañarcillo.

After completing this work, he made, in March, 1859, a barometrical and instrumental survey of the San Francisco pass of the Cordillera, starting from the Copiapo Valley and passing up the Paipote Valley. This was a distinguished service, and was ably performed, his report of this work being read before the Royal Geographical Society of England, where it excited much interest.

He made a visit to the United States in 1859, returning later in the same year to Chili, and was for some time interested in contracting on the Copiapo Road.

In 1861 he was associated with Mr. Henry Meiggs on the Santiago and Valparaiso road in Chili, and left there in the spring of 1862 for the United States, with the intention of entering the army. In the following autumn he was commissioned as Second Lieutenant in the First Massachusetts Cavalry. He was present at the battle of Fredericksburg, and also at Gettysburg, and, with his command, was engaged in a number of actions of minor importance, his company losing heavily, although he himself was so fortunate as only to be wounded once, and that slightly. From March, 1864, to the end of the war, he was attached to Gen. Meade's escort, and was in command of it towards the last, taking part in many memorable events, and being present at the famous review in Washington, the closing scene of the war. His rank when mustered out was Major, and he afterwards was breveted Colonel for brave and meritorious services during the war.

Colonel Flint's services throughout the war were notable for able administration of the delicate duties connected with his position upon the staff of the General in command, and for untiring solicitude for the welfare of his men, and for personal courage in service. His General and his companions in arms speak of him in enthusiastic and laudatory terms. After the close of the war he went to California, early in 1866, and was there engaged in making surveys of projected roads, and late in the year he accepted the position of one of the trustees of the Union Copper Mine at Copperopolis, and afterwards became its President.

Early in 1868 he was engaged on the Floating Dock at Hunter's Point, and later in the year made the surveys for the Los Angeles and Wilmington Railroad, and after its construction he remained for some time in charge as Superintendent.

In 1870 he was appointed Chief Engineer of the Western Division of the Northern Pacific Railroad, with headquarters at Portland, Oregon, and as such he had charge of the surveys in the State of Oregon, and in Washington, Idaho, and Montana Territories.

In 1871 he undertook exploration and preliminary surveys in the Indian Territory for the Atlantic and Pacific Railroad.

In April, 1872, he returned to South America as Chief Engineer of the Juliaca and Cuzco Railroad in Peru, having charge of the location of the road and of its construction so far as it was built.

In 1874 he became Superintendent of the Mollendo and Arequipa and of the Arequipa and Puno Railroads, and held those positions until 1877, when he returned to the United States.

In 1878 and 1879 he was Division Engineer in charge of construction in Nebraska on the Burlington and Missouri River Railroad, and was Chief Engineer of the Toledo, Cincinnati and St. Louis Railroad in 1883 and 1884.

In December, 1867, he was married to Miss Lucy Whitwell Parker, a daughter of the late William Parker, C. E., who with two sons and two daughters survive him.

Such is the mere skeleton, as a record of dates, and official appointments always is, of a career which needs in addition the flesh and blood of social and professional life, and of distinctive traits of character to constitute the man as he was known to his friends.

In his profession he leaves a long record of varied and responsible work ably performed. In the memory of those who knew him, and in the future lives of those whose youth was passed within the range of his personal influence, he leaves a monument scarcely less enduring.

Of the most sterling and spotless character, he himself knew no guile, and could hardly suspect it in another. His generosity and magnanimity left no room for malice or enmities, and his chivalry of sentiment and grace of manner were so thoroughly a part of the man that it was beyond the power either of prosperity or misfortune to affect them.

Colonel Flint was elected a Member of the American Society of Civil Engineers May 18th, 1870.

NOTE.—Committee preparing Memoir: James R. Maxwell, M. Am. Soc. C. E., and the Secretary.

American Society of Civil Engineers.

PROCEEDINGS.

Vol. XII.—November, 1886.

MINUTES OF MEETINGS.

(Abstract of such as may be of general interest to members.)

OF THE SOCIETY.

November 3d, 1886.—The Society met at 20 o'clock, Vice-President Rowland in the chair; John Bogart, Secretary. Ballots were canvassed and the following candidates declared elected. As Members: Alexander Gordon Brinckerhoff, Brooklyn, N. Y.; Chambers McKibbin Craig, Jeffersonville, Ga.; Wilbur Fisk McClure, Los Angeles, Cal.; William Lawrence Saunders, New York, N. Y. As Juniors: Christopher Newton Brown, Columbus, O.; Elijah Polhill Butts, Omaha, Neb.

A paper by Robert L. Harris, M. Am. Soc. C. E., Some Notes of a Recent Visit to the St. Lawrence Bridge Now Being Constructed at Lachine, Canada, was read and discussed. Remarks on the proposed drainage of the Valley of Mexico were made by Señor Gayol, City Engineer of the City of Mexico. Captain A. E. Piorekowski, of Germany, explained the principles, tests and efficiency of the Gruson type of chilled cast-iron armor for land batteries.

November 17th, 1886.—The Society met at 20 o'clock, President Henry Flad, in the chair; John Bogart, Secretary.

A paper by Edward Bates Dorsey, M. Am. Soc. C. E., on Irrigation, was read and discussed.

OF THE BOARD OF DIRECTION.

Novemrer 10th, 1886.—Applications were considered. The preparation of the Annual Report was directed. Appropriations were made. The subject referred to the Board by the last Convention, with communication in regard to reorganization, was considered.

LIST OF MEMBERS.

ADDITIONS.

HONORARY MEMBER. Date of Election.

DUANE, JAMES C.....Chief of Engineers, Bvt. Brig.-Gen., U. S. A., Washington, D. C.....Nov. 20, 1886.

MEMBERS.

ARTINGSTALL, SAMUEL GEORGE..City Engineer, Chicago, Ill.....Oct. 6, 1886.

CORNELL, GEORGE BIRDSALL ....(Elected Junior Aug. 6, 1879), Chief Engineer Brooklyn Elevated R. R., 49 Fulton st., Brooklyn, N. Y..... .Oct. 6, 1886.

CRAIG, CHAMBERS MCKIBBEN... Dublin, Ga.....Nov. 3, 1886.

CROSBY, BENJAMIN LINCOLN.....(Elected Junior June 2, 1880), Resident Engineer Rulo Bridge, Rulo, Neb.....Oct. 6, 1886.

DAGRON, JAMES GUSTAVUS.....Chief Inspector of Bridges, Baltimore and Ohio R. R., Baltimore, Md.. .....Oct. 6, 1886.

FOX, STEPHENSON WATERS.....(Elected Junior July 7, 1870), U. S. Engineer's Office, St. Joseph, Mo.....Oct. 6, 1886.

GREEN, BENJAMIN DWIGHT.....P. O. Box 95, Savannah, Ga.....Nov. 4, 1885.

HOLBROOK, FREDERICK WILLIAM DOANE.....Division Superintendent Northern Pacific R. R., Glendive, Montana.....Oct. 6, 1886.

HUNT, ALFRED EPHER.....98 Fourth Ave., Pittsburgh, Pa..Sept. 1, 1886.

LEDERLE, GEORGE ANTHONY.....(Elected Junior May 2, 1883), Resident Engineer Omaha Bridge, Omaha, Neb.....Oct. 6, 1886.

LOREE, LEONOR FRESNEL.....Engineer Maintenance of Way 2d and 4th Division, Chicago, St. Louis and Pittsburgh Ry., Logansport, Ind .....Oct. 6, 1886.

MASON, SAMPSON DOUGLAS .....Principal Assistant Engineer Northern Pacific R. R., St. Paul, Minn.....Oct. 6, 1886.

MCCLURE, ROBERT JOHN.....Consulting Engineer, Chicago, Burlington and Quincy R. R., Denver, Colo.....Oct. 6, 1886.

MCCLURE, WILBUR FISK.....134 N. Main st., Los Angeles, Cal..Nov. 3, 1886.

Date of Election

MORLEY, JAMES HENRY... .....Room 7, Temple Building, St. Louis, Mo..... .....Oct. 6, 1886.

PARSONS, HENRY CUYLER.....State Engineer's Office, Albany, N. Y..... .....Oct. 6, 1886.

PETRY, ALFRED.....Assistant Engineer Kentucky Central Ry., Covington, Ky..Oct. 6, 1886.

RUTHERFORD, FRANCIS MORRIS..Assistant Supervisor Pennsylvania R. R., Bordentown, N. J..Oct. 6, 1886.

SAMPLE, JOHN HENDERSON.....Chief Engineer Kansas and Colorado Ry., Salina, Kan.....Oct. 6, 1886.

SAUNDERS, WILLIAM LAWRENCE..Engineer Ingersoll Rock Drill Co., 10 Park place, New York City.....Nov. 3, 1886.

SHERMAN, RICHARD WILLETTE...City Surveyor, 36 Broad st., Utica, N. Y.....Oct. 6, 1886.

SMITH, MILLER ARMSTRONG.....224 Keap st., Brooklyn, N. Y...Oct. 6, 1886.

ASSOCIATES.

HANDY, FRANK W.....Minneapolis, Minn..... ....Oct. 6, 1886.

MCKINNEY, ROBERT COCHRAN ...Secretary and Assistant Manager Niles Tool Works, Hamilton, Ohio.....Oct. 6, 1886.

STONE, WATERMAN.....Superintendent Providence, Warren and Bristol R. R., Providence, R. I.....Dec. 1, 1886.

JUNIORS.

BOGGS, EDWARD MARSHALL. ...Colorado Midland Ry., Colorado Springs, Colo..... .....Oct. 6, 1886.

BROWN, CHRISTOPHER NEWTON..Assistant Professor Civil Engineering, Ohio State University, Columbus, Ohio .....Nov. 3, 1886.

BUTTS, ELIJAH POLHILL.....St. Cloud, Minn.....Nov. 3, 1886.

EDES, WILLIAM CUSHING.....Assistant Engineer Southern Pacific Co., Berryvale, Cal.....Sept. 1, 1886.

HOPPER, JOHN JACOB.....161 West 122d st., New York City.....May 5, 1886.

LAWLER, FRANCIS DENIS HUBERT..Engineer Iowa Lines, Chicago, Burlington and Quincy R. R., Burlington, Iowa .....Oct. 6, 1886.

CHANGES AND CORRECTIONS.

MEMBERS.

BAKER, WILLIAM H.....Resident Engineer Atchison, Topeka and Santa Fé R. R., New Kiowa, Kansas.

BALLARD, ROBERT.....Rockhampton, Queensland, Australia.

BARNARD, JOHN F.....President and General Manager Ohio and Mississippi Ry., Cincinnati, Ohio.

BELL, HENRY P.....Esquimault and Nanaimo Ry., Victoria, British Columbia.

BENYAURD, WILLIAM H. H.....Major Corps of Engineers U. S. A., San Francisco, Cal.

CARTWRIGHT, ROBERT.....237 Alexander st., Rochester, N. Y.

CHITTENDEN, SAMUEL H.....East River, Conn.

CLEMENT, FRANK H.....General Superintendent Juragua Iron Co., (Ltd.) Santiago de Cuba (208 South 4th st., Philadelphia, Pa.)

CROWELL, J. FOSTER.....Engineer of Construction Cincinnati and Richmond R. R., (Pennsylvania Co.) Room 6, Little Miami Depot, Cincinnati, Ohio.

DOANE, WALTER A.....Canadian Pacific R. R. Office, Sherbrooke, Quebec, Canada.

DORAN, FRANK C.....Indianapolis Union Ry. Co., Indianapolis, Ind.

EAYRS, NORMAN W.....(Care St. Louis Bridge and Tunnel R. R.) St. Louis, Mo.

FORNEY, MATTHIAS N.....23 Murray st., New York City.

FOUQUET, JOHN D.....Assistant Engineer and Superintendent Buildings New York, West Shore and Buffalo Ry., 444 West 57th st., New York City.

GOAD, CHARLES E.....53 New Broad st., London, E. C., England.

GOULD, E. SHERMAN.....Consulting Engineer Scranton Gas and Water Co., Scranton, Pa.

GRISWOLD, FRANK L.....Ferro-Carril de Buenos Aires a Marcedes (Clark & Co.), 31 Calle Rivadavia, Buenos Ayres, Argentine Republic.

HASELL, BENTLEY D.....(B. D. Hasell & Co.) 66 Pine st., New York City.

HUNT, RANDELL.....Waterloo, Iowa.

JENNINGS, WILLIAM T.....Engineer and Manager Construction Western Ontario Pacific Ry., London, Ontario, Canada.

MARR, GEORGE A.....U. S. Engineer's Office (P. O. Box H), St. Paul, Minn.

MCKEE, SAMUEL B.....Division Engineer Canadian Pacific R. R., Lenoxville, Quebec, Canada.

MOULTON, MACE.....Engineer of Bridges Colorado Midland R. R., Colorado Springs, Colo.

NICHOLS, OTHNIEL F.....Principal Assistant Engineer Suburban Rapid Transit Co., 845 East 164th st., New York City.

NOBLE, ALFRED.....Resident Engineer Harlem River Bridge, High Bridge, N. Y.

O'ROURKE, JOHN F.....Chief Engineer Union Bridge Co., in charge Poughkeepsie Bridge, Poughkeepsie, N. Y.

OSGOOD, JOSEPH O.....Chief Engineer Toledo, St. Louis and Kansas City R. R., Toledo, Ohio.

PAINE, ARTHUR B.....Chief Engineer Manhattan Bridge Building Co., Poughkeepsie, N. Y.

PARKHURST, HENRY W.....(Care Geo. S. Morison), 35 Wall st., New York City.

RICHARDSON, THOMAS F.....2217 Champa st., Denver, Colo.

ROWE, SAMUEL M.....Resident Engineer Atchison, Topeka and Santa Fé R. R., 261 Topeka ave., Topeka, Kansas.

SAWYER, CHARLES H.....Assistant Engineer Union Pacific Ry., Stanberry, Mo.

SEARS, CLINTON B.....Capt. Corps of Engineers U. S. A., Bismarck, Dakota.

SIMPSON, GEORGE H.....Terre Haute, Ind.

SKINNER, FRANK W.....(Care Pottsville Iron and Steel Co.) Pottsville, Pa.

SMITH, W. HARRISON.....Engineer American Manganese Co. (Ltd.) Mushet P. O., Augusta Co., Va.

STALEY, CADY.....President Case School Applied Science, Cleveland, Ohio.

STEARNS, FREDERIC P.....Chief Engineer State Board of Health, 13 Beacon st., Boston, Mass.

STANTON, ROBERT B.....Flint, *via* Silver City, Idaho.

STRIEDINGER, JULIUS H.....(Care Paul Lorent, German Consul), Bucaramanga, Santander, U. S. Colombia.

THACKRAY, GEORGE E.....Superintendent Columbus Steel Co., Columbus, Ohio.

WARE, R. WILLARD.....Plainfield, N. J.

WALLACE, JOHN F.....Assistant Engineer Union Pacific Ry., Fort Steel, Wyoming.

WALKER, J. S.....Box 16, Birmingham, Ala.

WARDLAW, JAMES R.....25 Chambers st., Room 25, New York City.

WATKINS, FREDERICK W.....Superintendent Construction Ohio Valley Ry., Henderson, Ky.

WHEELER, LEVI L.....2828 Washington ave., St. Louis, Mo.

ASSOCIATES.

ANDREWS, EDWARD R .....Equitable Life Assurance Co., Boston, Mass.
DANA, JAMES J.....Lt.-Col., Bvt. Brig.-Gen. U. S. A., President Hastings Pavement Co., 1913 J st., Washington, D. C.
PHILLIPS, HENRY A.....Division Superintendent Fitchburg R. R., Worcester, Mass.

JUNIORS.

BRERETON, THOMAS J .....Assistant Supervisor Pennsylvania R. R., Monongahela, Pa.
DAY, G. FREDERICK P.....Los Angeles, Cal.
HAINES, CASPER W.....(Care R. B. Haines), Cheltenham, Pa.
HAVILAND, ARTHUR .....Assistant City Engineer, San Antonio, Texas.
SEAMAN HENRY B.....3205 Baring st., Philadelphia, Pa.
STARR, WILLIAM H.....Superintendent's Office Eastern Div. New York, Lake Erie and Western R. R., Jersey City, N. J.
WEISKOPF, SAMUEL C .....(Care Keystone Bridge Co.), Pittsburgh, Pa.
YOUNG, HERBERT A .....Division Engineer Toledo, St. Louis and Kansas City R. R., Frankfort, Ind.

DEATHS.

CORYELL, MARTIN.....Elected Member December 4, 1867; died November 30, 1886.
ELLIOTT, GEORGE H.....Elected Member April 4, 1883; died October 7, 1886.
EVANS, WALTON W.....Elected Member December 4, 1867; elected Fellow March 15, 1870; died November 28, 1886.

American Society of Civil Engineers.

PROCEEDINGS.

Vol. XII.—December, 1886.

MINUTES OF MEETINGS.

(Abstract of such as may be of general interest to members.)

OF THE SOCIETY.

December 1st, 1886.—The Society met at 20 o'clock, Vice-President Rowland in the chair; John Bogart, Secretary. Ballots were canvassed and the following candidates declared elected. As Members: William Jewett Haskins (elected Junior March 7th, 1883), New York City; William Chatlin Wetherill, Liberty, Mo. As Associate: Waterman Stone, Providence, R. I. As Junior: Ralph Modjeski, Omaha, Neb.

The death on November 28th, 1886, of Walton White Evans, M. Am. Soc. C. E., and F. Am. Soc. C. E., and the death on November 30th, 1886, of Martin Coryell, M. Am. Soc. C. E., were announced.

The report of the Committee on the Compressive Strength of Cement and Settlement of Masonry, which was presented at the Annual Convention, was discussed.

A paper by Henry Faija, C. E., on Portland Cement Testing, was read and discussed. A paper on the Effect of Freezing on Cement-Mortar, by Alfred Noble, M. Am. Soc. C. E., was read and discussed.

Mr. Edward P. North, M. Am. Soc. C. E., exhibited and described some of the tubes used and proposed to be used in electrical subways.

December 15th, 1886.—The Society met at 20 o'clock, Mr. E. B. Van Winkle in the Chair; John Bogart, Secretary.

A paper by R. E. McMath, M. Am. Soc. C. E., on the Determination of the Size of Sewers, was read. A paper by James B. Francis, Past President Am. Soc. C. E., on the Stoppage of Flow in Water Mains by Anchor Ice, was read and discussed.

OF THE BOARD OF DIRECTION.

DECEMBER 8TH, 1886.—Applications were considered. Action was taken as to the issue of a circular in accordance with resolution adopted at the Denver Convention in reference to Changes in the Organization of the Society. Action was taken in reference to methods of ventilating the building and in reference to securing the professional records of Members whose records are not upon the files of the Society.

Arrangements for the Annual Meeting were made and a committee appointed on the subject. Appropriations were made.

MEMOIRS OF DECEASED MEMBERS.

HENRY MORSE WIGHTMAN, M. Am. Soc. C. E.

DIED APRIL 3D, 1885.

Henry Morse Wightman, born in Boston, Mass., January 5th, 1840, was the son of Joseph Milnor and Bethiah (Morse) Wightman. His father was a well known maker of philosophical instruments, was Mayor of Boston in 1861 and 1862, and subsequently became a member of the Bar.

Henry M. Wightman was educated in the Boston Public Schools, graduating at the English High School in 1857. Shortly afterward he entered the City Engineer's Office as rodman, James Slade then being City Engineer. He served for several years in a subordinate capacity upon the various engineering works of the city, such as the improvements of the bridges, water supply and public grounds. In 1861 and 1863 he made surveys in connection with the extension and protection of the water supply at Lake Cochituate, and in 1864 acted as engineer for the Back Bay Commissioners; but he was principally employed from 1860 to 1864 upon the Public Garden improvement, where he was in charge of the work as Assistant Engineer. From 1864 to 1870 he was chiefly occupied with the surveys and construction of the Chestnut Hill Reservoir, the largest and finest in the suburbs of Boston. He was Resident Engineer on this work from February 14th, 1866, till its completion in 1870. On his return to the city office in May, 1870, he was

Committee to prepare Memoir: William Jackson, Eliot C. Clarke and Fred. Brooks, Members Am. Soc. C. E.

appointed Assistant City Engineer, and remained in that position ten years. Upon the resignation, in 1880, by Joseph P. Davis, M. Am. Soc. C. E., of the office of City Engineer, Mr. Wightman was chosen to succeed him, and held the office till death. In this capacity he had charge of the construction and maintenance of most of the public works of the city, and attended to the multifarious and engrossing matters of business connected therewith. Among the more important works of which he had charge were included the completion of the Main Drainage Works begun under his predecessor; the completion of the works for bringing an additional supply of water from Sudbury River to the city; the construction of a new storage reservoir at Ashland; and grading, road-making, and bridging for the new public parks.

Mr. Wightman made an excursion to North Carolina in the spring of 1885, and came home suffering from pneumonia. The disease suddenly took an unfavorable turn a week later, when he died, April 3d, 1885, at his home in Boston.

Mr. Wightman's career was one of steady progress from the lowest to the highest place in the Boston City Engineer's Office. All his work was done thoroughly, though often under embarrassing circumstances occasioned by city politics. In such cases his business tact and knowledge of men, and of the best way of managing them, were very useful to the city. He accomplished the essential result of getting work well done, yet avoided wrangling and litigation. The reliance which was placed upon his judgment was shown by his being frequently employed as a referee in cases of controversy, and often consulted upon engineering questions outside the duties of his office. He had a natural constructive faculty by which he appeared to see instinctively whether a structure was well proportioned, and whether work was being well handled. Perhaps the leading and most instructive trait of his professional character was his executive ability. His decisions were definite, final and generally prompt; and when he entrusted authority to his subordinates he upheld them in its exercise. Where a man less fortunately constituted might have succumbed to overwork, he was saved by a happy faculty which kept him from worrying, and enabled him to stop thinking about his work when thinking about it could do no good. He was also favored by the possession of social qualities which made him an agreeable companion. He was of the greatest service to his parents and to his sisters.

Mr. Wightman was elected a member of the American Society of Civil Engineers April 2d, 1873; and he served as Chairman of the Local Committee when the Society held its Convention at Boston in 1878.

ADDITIONS TO

LIBRARY AND MUSEUM.

From W. F. Allen, Secretary General Time Convention, New York City:

Proceedings of the General Time Convention held at the Hotel Brunswick, New York City, October 13th and 14th, 1886.

From Allen Paper Car Wheel Company, New York City:

Description of the Allen Paper Car Wheel, with Plates.

From American Institute of Electrical Engineers, Ralph W. Pope, Secretary, New York City:

Transactions, Vol. III.

From American Institute of Mining Engineers, Dr. R. W. Raymond, Secretary, New York City:

The Geology and Vein Structure of Southwestern Colorado. Theo. B. Comstock.

Lode Locations. R. W. Raymond.

The Irregularities of the Blast-furnace Process, and a Practical Way to Avoid Them.

The Diamond Mines of South Africa. Gardner F. Williams.

The Attainment of Uniformity in the Bessemer Process. H. M. Howe.

The Ives Process of Photo-Mechanical Engraving, and its Usefulness to Engineers. R. W. Raymond.

Note on the Opening of a Chilled Hearth with Coal Oil Blow-pipe.

The Iron Ores and Coals of Alabama, Georgia and Tennessee.

Large Charges *vs.* Small Charges at Warwick Furnace.

Proceedings St. Louis Meeting.

The Dunnachie Continuous Regenerative Gas Kiln for Burning Fire brick, Pottery, etc. Thomas Egleston.

American Mining Schools. Prof. R. H. Richards.

An Improvement in Apparatus for the Manufacture of Sulphuric Acid. W. H. Adams.

Discussion of Mr. Walch's Paper on the Irregularities of the Blast Furnace. James E. Mills.

Titanium Carbide in Pig Iron. Porter W. Shimer

Tests of Manganese Steel. Joseph D. Weeks.

The Condition of Silver in a Sample of Litharge. Prof. Charles E. Wait.

Two Conditions of Phosphorus in Iron. Byron W. Cheever.

Sierra Mizada, Mexico. Richard E. Chism.

The Geological Map of the United States. C. H. Hitchcock.

The Genesis of Certain Ore Deposits. S. T. Emmons.

Comparisons of Blast Furnace Records. John Birkinbine.

Russell's Improved Process for the Lixiviation of Silver Ores in its Practical Application.

Geological Map of the United States and part of Canada.

From American Iron and Steel Association, Philadelphia, Pa.:

Directory to the Iron and Steel Works of the United States for 1886.

Twenty-one Years of Progress in the Manufacture of Iron and Steel in the United States. James M. Swank.

From M. D. Banderali, Paris, France:

Les Chemins de fer Métropolitains a New York and Dans les Grandes Cities Américains.

From Carrol Ph. Bassett, Newark, N. J.:

Contract for Sewers and Appurtenances, East Orange, N. J.

From Edwin F. Bedell, New York City:

Framed Photographs of Draw-bridge over the Harlem River at Second Avenue, New York.

From E. S. Bellasis, London, England:

A Paper on the Roorkee Hydraulic Experiments, with an Abstract of the Same. E. S. Bellasis, Assoc. M. Inst. C. E.

From H. Bissell, Sa'em, Mass.:

Fifty-third Annual Report of the Boston and Maine Railroad for the Year ending September 30th, 1886.

From D. E. Bishop, New York City:

Field Notes, etc., of the third railroad built in the United States in 1829. Ithaca and Oswego Railroad.

From C. R. Boyd, Wytheville, Va.:

Map of Southwest Virginia and Contiguous Territory.

Mineral Resources and Railway Facilities.

From Bureau of Education, Washington, D. C.:

Special Report by the Bureau of Education and Educational Exhibits and Conventions at the World's Industrial and Cotton Centennial Exposition, New Orleans, 1884-85, Part I.

From Bureau of Navigation, Navy Department, Washington, D. C.:

Pilot Chart of the North Atlantic Ocean for September, October, November and December, 1886.

From H. W. Brinckherhoff, Brooklyn, N. Y.:

Plans and Sections of the Obelisk on Bunker Hill, with the Details of Experiments made in Quarrying the Granite.

From B. S. Church, New York City:

Reports of Examining Engineers on the charges preferred against the Chief Engineer of the Aqueduct Commission (Copies for distribution.)

From Eliot C. Clarke, Boston, Mass:

Prevention of Floods in the Valley of Stone Brook.

From Chief of Engineers U. S. A., Washington. D. C.:

Advertisements, Instructions, Specifications and Proposals as follows:

For Furnishing Timber, Plank or Edgings at Carrolton Bar, Saginaw River, Mich.

For Improvement of Chickahominy River, Va.
For Improvement of York River, Va.
For Improvement of Potomac River near Washington, D. C.
For Improvement of Potomac River near Washington, D. C., Tidal Reservoir.
For Improvement of Inland Navigation from New Berne to Beaufort Harbor *via* Clubfort, Harlowe and Newport Rivers, N. C.
For Improving Calcasieu River and Pass, La.
For Improving Tchefuncte River, La.
For Removing Ledge from the Cochew River, N. H.
Improving Susquehanna River, Md., above the Baltimore and Philadelphia Railroad Bridge.
Extending the Pile Dike at the Mouth of the Passaic River, N. J.
Improvement of Santee River, S. C, and its outlet through Mosquito Creek.
Improvement of New River, N. C.
For Constructing Dike between Hog and Maiden Islands, Delaware River.
Improvement of Potomac River near Washton, D. C., Washington Channel.
Dredging Saginaw River, Mich.
Dredging West of Petty's Island, Delaware River.
Furnishing and Placing Stone in revetment across Smith's Island Bar.
Improvement of Schuylkill River, Pa.
Dredging at Smith's Island Bar between Philadelphia and Camden, Delaware River.
Dredging in James River, Va.
For Furnishing Piles and Pile-Driving; Furnishing Timber, Plank and Edging, and Iron Bolts, Spikes and Nails for Repairs of Beam Wall and Revetment at Carrollton Bar, Saginaw River, Mich.
For Dredging Norfolk Harbor, Va., and approach to same.
Improvement of San Joaquin River, Stockton and Mormon Sloughs, Cal.
For Dredging and Rock Excavation; Construction of Mattress-Dikes; and Construction and Extension of Jetties.
For Furnishing Lumber for Bulkhead Piers and Coffer-Dams at Saint Mary's Falls Canal, Mich.
For Furnishing and Placing Puddling Clay for a Coffer-Dam at Saint Mary's Falls Canal, Mich.
For Furnishing Iron Draft Bolts and Spikes at Saint Mary's Falls Canal, Mich.
For Furnishing One Dredge, One Tug and Two Dump Scows for use at Saint Mary's River and Saint Mary's Falls Canal, Mich.
For Framing, Placing, Filling and Completing Crib-piers for Bulkheads and Coffer-Dam at Saint Mary's Falls Canal, Mich.
For South Pier Extension, Calumet Harbor, Ill.
For Removing Rock in Portsmouth Harbor, N. H.
Improving Harbor at Georgetown, S. C.
Improvement of Wilmington Harbor, Cal.
Dredging at Ogdensburg Harbor, N. J.
For Stone for Breakwater, Saco River, Me.
Improving Harbor at Wilmington, Del.
Improvement of Inland Waterway between Beaufort Harbor and New River, N. C., through Bergen Sound.
Improving Cape Fear River, N. C., below Wilmington.
Construction of Breakwater at Rouse's Point, Lake Champlain, N. Y.
Dredging at Kenyon's Bay and Rock Excavation at Elbow, near Whitehall, N. Y.
Ohio River Improvement, Davis Island Dam.
For Furnishing Material and Doing the Work of Repairs to Gilbert's Island Dam, Denmark Island Dam, Cincinnati Landing Chute, Wing Dams and other Shore Protections.
For Furnishing and Delivering Brush Harbor at New Orleans, La.
Improvement of Breton Bay, Md.
Improvement of Potomac River near Washington, D. C. Rip-rap Stone.
Improvement of Volusia Bar, Fla.
Improving Channel Over the Bar at the Mouth of St John's River, Fla.
Harbor Improvement Saint Joseph, Mich.
For Constructing Wharves in the Harbor of Refuge at Woods Hole, Mass.
Improvement of Harbor at Savannah, Ga.
Improving Harbor at Norfolk, Va., Approach to Norfolk Harbor and the U. S. (Norfolk) Navy Yard, Va., Currituck Sound, N. C, and North River Bar, N. C.
For Superstructure and Repairs of Pier Kenosha Harbor, Wis.
For Improvement of Brunswick Harbor, Ga.
For Improvement of Savannah Harbor and River, Ga.
For Improvement of Harbor at Charleston, S. C.
For Improvement of Brunswick Harbor, Ga.
For Construction of Breakwater, Harbor of Refuge, Milwaukee Bay, Wis.
For Superstructure and Repairs of Pier, Racine Harbor, Wis.
For Superstructure and Repairs of Pier, Milwaukee Harbor, Wis.
For Improvement of Mobile Harbor, Ala.
For Improvement of Michigan City, Indiana, Outer Harbor.
For Improving Channel Leading to Harbor at Baltimore.
For Dredging in Wareham Harbor, Mass.
For Dredging in Newport Harbor, R. I.
For Improvement of Cumberland Sound, Ga. and Fla.
For Improving Appomattox River, Va.
For Removing Ledge of Solid Rock and Boulders from Detroit River.
For Furnishing Rope, Boat, Supplies, etc., for Great Kanawha River Improvement.
For Removal of the Wreck of the Schooner "B." Oliphant, in Chesapeake Bay.
For Completing No. 6 Lock House, Great Kanawha River Improvement.
For Building the Dam and Abutment at Lock No. 2, Great Kanawha River, W. Va.
For Furnishing Timber and Plank and Iron Plates, Bolts and Spikes, for Repairing Crib-Work at the Harbor of Refuge at Sand Beach, Mich.
For Furnishing Piles at Government Works in the Mississippi River, between St. Louis and Harrisonville.
For Furnishing Screw-Bolts at the United States Engineer Depot, foot of Arsenal Street, in St. Louis, Mo.
For Furnishing Spikes, Iron and Nails at the United States Engineer Depot, foot of Arsenal Street, in St. Louis, Mo.
For Furnishing Manila Rope at the United States Engineer Depot, foot of Arsenal Street, in St. Louis, Mo.

For Excavating at Middle Neebish, Hay Lake Channel, Mich.
For Dredging in Flushing Bay, N. Y.
For Dredging in New London Harbor, Conn.
For Increasing Height of East Jetty at Saybrook, Conn.
For Extending the New Haven Breakwater.
For Dredging in Bridgeport Harbor, Conn.
For Extending the Dike in New Haven Harbor, Conn.
For Dredging in Black Rock Harbor, Conn.
For Dredging in Norwalk River, Conn.
For Dredging in Hyannis Harbor, Mass.; Pawtucket River, R. I.; Providence River, R. I.; Pawcatuck River, R. I. and Conn.; and the Removal of Green Jacket Shoal, Providence Harbor, R. I.
For Dredging in Lynn Harbor, Mass.
For Dredging and Blasting in Cituate Harbor, Mass.
For Dredging in Plymouth Harbor, Mass.
For Dredging in Ipswich River, Mass.
For Improving Harbor at Sabine Pass, Texas.
For Improving Hingham Harbor, Mass.
For Improving Oakland Harbor, Cal.
For Improving Harbor at Kewaunee, Wis.
For Improving Harbor at Port Washington, Wis.
For Improving Harbor at Manitowoc, Wis.
For Improving Harbor at Sheboygan, Wis.
For Improving Harbor at Grand Marais, Mich.
For Improving Harbor at Ontonagon, Mich.
For Rubble Stone for the Extension of North Jetty at Entrance to Newburyport Harbor, Mass
For Rubble Stone for Harbor of Refuge, Sandy Bay, Cape Ann, Mass.
For Increasing Height of Dike in the Connecticut River at Hartford, Conn.
For Constructing a Dike in the Thames River, Conn.
For Improving Potomac River near Washington, D. C., Dredging and Embankment.
For Rip-rap Stone for Potomac River near Washington, D. C.
For Dredging North River Bar, N. C.
For Proposed Wharf at Cascade Locks, Ore.
For Improving Choptank River, Md.
For Improving Corsica Creek, Md.
For Furnishing Rip-rap Granite for the Eastern Jetty at Nantucket, Mass., and the Eastern Breakwater at Stonington, Conn.
For Furnishing Stone for Use at the Des Moines Rapid Canal and Dry Dock.
For Extending the Breakwater at Greenport, N. Y.
For Removing Broken Rock from Middle Reef, or Flood Rock, Hell Gate, N. Y.
For Building Cribs and Rip-rapping Susquehanna River, Md.
For Removing Theiss Rock and Jetty Housatonic River, Conn.
For Engineer Supplies and Repair of Boat at Nantucket, Mass.
' or Decked Flat-boat.
For Fuel.
Removal of Wreck at Cape Henlopen, Del.
Furnishing and Placing Stone in the Gap, Delaware Breakwater.
Instructions to Bidders.
Bridge over the Ohio River at or near Cairo, Ill.
A Statement Relative to the Kentucky and Indiana Bridge Company.
To the Utility of a Breakwater at Gordon's Landing, Lake Champlain.
Reports Relative to Filters for the Water Supply for the Capitol.

From William A. Crafts, Boston, Mass.:
Seventeenth Annual Report of the Board of Railroad Commissioners of Massachusetts, January, 1886.

From Joseph P. Davis, New York City:
Journal of the Franklin Institute. Vol. XLI, 1861, to Vol. XC, 1885, bound. January to August, 1885, unbound.
Plates to Illustrate Macaulay's Treatise on Field Fortification, and other subjects connected with Field Engineering.
A Hand-book for Plain and Ornamental Mapping and Engineering Drawing.
Long and Short Span Railway Bridges, John A Roebling.
Designs for Tall Chimney Shafts. R. Rawlinson.
American Bell Telephone Company *vs.* Overland Telephone Company of New York. Defendant's Answer and Proof on Motion for Injunction,
The American Bell Telephone Company and Others *vs.* The People's Telephone Company and Others. Defendant's Sur-Rebutting Testimony.
Brief for Complainants on Final Hearing.
Arguments of Hon. Lysander Hill and Hon. George F. Edmunds, for the Defendants.
Opinion of Hon. Don A. Pardee and Hon. Edward C. Billings, granting Complainant's Motion.
Abstract of Testimony.
A Sketch of a Physical Description of the Universe. Volumes I, II, III, IV and V. Alexander Von Humboldt.
Report on the Explosions of Steam Boilers. Part II.
Annual of Scientific Discoveries for 1869 and 1870.

Protection against Fire and the Best Means of Putting out Fires in Cities, Towns and Villages.
The Art of Brewing Ale, Beer and Porter.
A Treatise on the Construction and Management of Railways.
Rifle and Light Infantry Tactics. Volumes I and II.
The Contractors' Manual and Builders' Price Book.
A Treatise on Field Fortifications.
The Slide Valve Practically Considered.
Steel Engraving of Gate-house at Farm Pond, Boston Water-works. Sudbury River Conduits.
Plans of Hydrants and Stop-cocks.
Plans, Profiles, for Crossing of New Croton Aqueduct under the Harlem River.
Sixteen Maps of the Peruvian Guano Islands. Surveyed by Joseph P. Davis, M. Am. Soc. C. E.
General Specifications for Pumping Engines to Govern Designs Accompanying Proposals.

From G. F. Deacon, Liverpool, England;
Annual Report of the Engineer as to the Progress of the Works of the City of Liverpool Corporation Water-works.
Second Report of the Special Sub-Committee of the Water Committee on the Proposed Supply of Water from the River Vyrnwy.
Report of the Special Committee on the New Water Supply.

From J. H. Decker, Secretary American Water-works Association, Hannibal, Mo.:

Report of Proceedings of the Sixth Annual Meeting of the American Water-works Association, held at Denver, Colo., June 23, 24 and 25, 1886.

From Dr. Daniel Draper, Director New York Meteorological Observatory, Central Park, New York City:

Memoir of John William Draper, 1811-1882.

From Edward Bates Dorsey, New York City:

Colorado: its Gold and Silver Mines, Farm and Stock Ranges, and Health and Pleasure Resorts.

Annual Report upon the Geographical Surveys of the Territory of the United States, West of the 100th Meridian.

Report on Bridging the Misssisippi River between St. Paul, Minn., and St. Louis, Mo.

The Bartholdi Statue: History and Description.

Annual Reports of the Philadelphia, Wilmington and Baltimore Railroad Company for the Years 1883 to 1885, inclusive.

Twenty-third Annual Report of the Directors of the old Colony Railroad Company, November 23, 1886.

Fourteeth Annual Report of the Atchinson, Topeka and Santa Fé Railroad Company for the year euding December 31, 1885.

From H. A. Duc., Jr., Charleston, S. C.:

Ten Photographs taken after the Earthquake, and Samples of Sand as follows:

Earthquake Ruins of Mr. August Melin's Room, 21 King street, Charleston, S. C.

Fissure at the Ten Mile Hill.

Cumberland and East Bay Street.

Hibernian Hall

Hole on St. Phillip and Green Street.

Track out of Line.

Hayne Street.

Old Hospital.

Two Photographs of Fissures.

Precipitated Matter from the Water which flowed from Fissures at the Ten Mile Hill.

Sample of Rice from the vicinity of the Fissures near Ten Mile Hill.

Shell Lime from the Chimney of an Old House over 100 years old on the lot of H. A. Duc, Jr.,

Samples of Sand from the Earthquake Fissure at Ten Mile Hill near Charleston, S. C. (12 different samples).

Sample of Shell Lime from the old Chimney Duc's House.

Ruins of Hibernian Hall.

From St. Michael's Church.

Sample of Micaceous Sand Extracted from a Fissure on the top of Ten Mile Hill, near Charleston (No. 1).

Sample of Sand lying on the top of No. 1 from same Fissure (No. 2).

Sample of Sand covering Nos. 1 and 2 from same Fissure (No. 3).

Samples of Undisturbed Soil adjacent to the Fissures from which samples Nos 1, 2 and were obtained.

Samples of Strata at the bottom of New Artesian Well, 920 feet deep. Well was not disturbed by the Earthquake.

From Dyckerhoff, Sohne, Amoenburg, Germany:

Protokoll der Verhandlungen des Vereins Deutscher Cement Fabrikanter und der Section für Cement des Deutschen Vereins Fabrikateon von Zigeln.

Thomvaaren Kalk und Cement 1880 and 1885, and Journal für Gaslebenchtung und Wasserversorgung 1886.

From Thomas Evershed, Rochester, N. Y.:

Water Power at Niagara Falls to be Successfully Utilized.

From M. N. Forney, New York City:

Photograph of Steam Tug New Jersey, with Description.

From E. B. Freeman, Norfolk, Va.:

The Preservation of Timber; or How to Prevent Decay and Preserve Timber against the Attack of the *Toredo Navalis* or Ship worm.

From E. A. Fuertes, Ithaca, N. Y.:

Cayuga Lake, N. Y., Surveyed by the Engineer Department, Cornell University.

From S. M. Gray, Providence, R. I:

Report Showing Location and Size of the Main and Intercepting Sewers of Providence, R. I.

From G, S. Greene, Jr., New York City:

Sixteenth Annual Report and Minutes of the Department of Docks for the Year ending April 30th, 1886; also Annual Report of Docks for 1886 and Minutes of the Board

From J. M. Goodwin, Sharpsville, Pa.:

Reports of the Engineers of the Western Railroad Corporation made to the Directors in 1836-37.

Annual Report of the Michigan Southern and Northern Indiana Railroad Company, March 1st, 1886.

A Letter to the Honorable Brockholst Livington on the Lake Canal Policy of the State of New York, with a Supplement and Additional Documents.

Report of Board Convened to Determine on a Standard for Construction of Pacific Railroad, made to Hon. James Harlan, Secretary of the Interior, February 24th, 1866, with Accompanying Documents.

Address of John W, Garrett, President, made on the 12th of February, 1868, at the Monthly Meeting of the Board of Directors of the Baltimore and Ohio Railroad Company.

From William Ham Hall, Sacramento, Cal.:

Irrigation Report of the State Engineer of California.

Irrigation Laws and Regulations in France, Italy and Spain.

Memorandum of the Irrigation Question.

From Wm. Hamilton, Toronto, Canada:

Annual Report of the City Engineer and Manager of the Toronto Water-works for the year ending 31st December, 1884.

From Institution of Civil Engineers, James Forrest, Secretary, London:

The Separation of Galena and Blende. Ernest Du Bois Lukis.

Footpaths. Henry Percy Boulnois.

On the Effects of Liquids on Iron. David Phillips.

The Maintenance of the Belah and Deepdale Viaducts on the North Eastern Railway. William John Cudworth.
Coefficients of Discharge Applicable to Certain Submerged Weirs of Large Dimensions. Robert Hunter Rhind.
The Stability of Voussoir Arches, Henry Albert Cutler.
Description of a Circular Chimney Shaft at Merchernich, near Cologne. John Mackworth Wood.
The Design and Stability of Masonry Dams. Walter Bulkeley Coventry.
The Mersey Railway. Francis Fox.
The Hydraulic Passenger Lifts at the Underground Station of the Mersey Railway. William Edmund Rich. (With an abstract of the discussion upon the paper.)
Brick-making. Henry Ward. (With an abstract of the discussion upon the paper.)
Modern Machine Tools and Workshop Appliances for the Treatment of Heavy Forgings and Castings. William Wilson Hulse. (With an abstract of the discussion upon the paper.)
Experiments on the Relative Strength of Cast-Iron Beams. Edward Carstensen De Segundo and Leslie Stephen Robinson.
On the Horizontal Range of Tidal Rivers, such as the river or well with reference to Sewage Discharge. Charles Foote Gower.
Experiments on a Direct Acting Steam-Pump. John George Mair.
Viaduct over the River Esk at Whitby, and the Embankments and Culverts in the Raimes. Francis Fox
On the Practical Strength of Columns and of Braced Struts. Thomas Claxton Fidler.
Heliography; or, the Actinic Copying of Engineering Drawings. Benjamin Howarth Thwaite.
The Bilbao Iron-works. Neil Kennedy.
The Gold Fields of South Africa. Sidney Howard Farrar.
Minutes of Proceedings. Vol. LXXXVI, 1885-86, Part 4.
Brief Subject Index Vols. LIX to LXXXVI.

From Institute of Engineers and Shipbuilders in Scotland. W. J. Millar, Secretary, Glasgow, Scotland:
Transactions, Vol. XXIX, 1885-86.

From Iron and Steel Institution, J S. Jeans, Secretary, London, England:
The Journal of the Iron and Steel Institution, No. 1, 1886.

From Dr. J. P. Janse, Scheveningen, Holland:
Procés-Verbaux des Seances du Congrès International de Navigation Intérieure tenue à Bruxelles, du 24 Mai au 2 Juin, 1885.
Memoires publiés à l'occasion du Congrès International de Navigation Interieure terne à Bruxelles, du 24 Mai an 2 Juin, 1885.
Examen des Travaux de la Commission des Canaux Brabancons por Janes de Blois.
Map of the Manchester Ship Canal, with a Description of the Plans Prepared for the Session 1885.
Bulletin du Canal Interoceanique, August 1, 1886.

From J. C. Kelton, Asst. Adjutant-General, U. S. A., Washington, D. C.:
Official Army Register for 1886.

From Marvin W. Kingsley, Cleveland, Ohio:
Thirteenth Annual Report of the Waterworks Trustees of the City of Cleveland, Ohio, for the year ending December 31, 1885.

From Charles Kilner Sheard, Tasmania:
Descriptive Paper of Railway Practice and Mountain Railways of a Similar Description to the Tasmanian Railways now under Construction.

From Konigliche Kommission, Berlin, Germany:
Mittheiungenaus den Koniglichen technischen der fuchsauftalten zu Berlin. Vols. I, II, III, IV, 1885, and Vols. I, II and III of 1886.

From J. Francis Le Baron, Jacksonville, Fla.:
The Desirability of the Establishment by the States of a True Polar Meridian and Standard of Length in each County.

From James MacNaughton, Albany, N. Y.:
The Expedition of the Alert to Hudson's Strait and Bay in 1885.

From Capt. O. E. Michaelis, West Troy, N. Y.:
Report of the Electrical Conference at Philadelphia in September, 1884.

From Robert Moore, St. Louis, Mo.:
Kutter's Formula and its Application to Circular Sewers.

From George S. Morison, New York City:
Vol. XX of the Tenth Census of the United States, 1880.

From Gilbert Murdoch, St. John, N. B., Canada:
Annual Accounts and Statements with Superintendent's and Auditor's Reports, of the Sewerage and Water Supply for the City of St. John (East Side), and Town of Portland for the year ending December 31, 1885.

From Robert Murray, Surgeon-General U. S. A., Washington, D. C:
Index Catalogue of the Library of the Surgeon-General's Office, United States Army. Vol. VII.

From Navy Department, Washington, D. C.:
Report on European Dock-yards. Philip Hickborn.

From New York Meteorological Observatory, Dr. Daniel Draper, Director, Central Park, New York City:
Abstract of Registers for Self-Recording Instruments for July, August, September, October, 1886.

From Professor Simon Newcomb, U. S. N., Superintendent American Ephemeris and Nautical Almanac, Washington:
The American Ephemeris and Nautical Almanac for the Year 1889.

From New York State Board of Health, Albany, N. Y.;
Bulletin of the State Board of Health for July, August, September and October, 1886.

From Joseph Nimmo, Jr., Huntington, N. Y.:

Sea-coast Defenses of New York City, Long Island, Staten Island and Connecticut.

From Edward P. North, New York City:
Fifth Annual Report of the Chicago, St, Paul, Minneapolis and Omaha Railway Company for the Year ending December 31st, 1885.
Annual Report of the Chicago and Northwestern Railway Company for the Twenty-seventh Fiscal Year, ending May 31st, 1886.
Second Annual Report of the Supervisory Board of Commissioners of the New York Municipal Civil Service.

From John L. Ogden, Philadelphia, Pa.:
Eighty-fourth Annual Report of the Chief Engineer of the Philadelphia Water Department for the Year 1885.

From Ordnance Department, General S. V. Benet, Chief, Washington, D. C.:
Ordnance Notes, Vol, XII.
Index to Ordnance Notes, Nos. 344 to 357 inclusive.

From Charles Paine, Pittsburgh, Pa.:
Something about Natural Gas: Its Origin, Extent and Development.

From H. V. & H. W. Poor, New York City:
Poor's Directory of Railway Officials and Railway Directors for 1886.

From Ernest Pontzen, Paris, France:
Studie Uber Die Wiener Stadtlahnen mit beziehung auf dei Entrichlung der Staat Wier.

From J. W. Powell, Director U. S. Geological Survey, Washington, D. C.:
Mineral Products of the United States Calendar-Year 1882-83-84 and 85.

From George W. Rafter, Rochester, N. Y.:
On the Use of the Microscope in Determining the Sanitary Value of Potable Water, with Special Reference to the Biology of the Water of Hemlock Lake.

From J. H. Setchel, Secretary American Railway Master Mechanics' Association, Dunkirk, N. Y.:
Report of Procedings of Seventeenth and Eighteenth Annual Conventions of the American Railway Master Mechanics' Association, 1884-85.
The First, Second, Third, Seventh, Eighth, Tenth, Eleventh, Twelfth, Thirteenth, Fourteenth, Fifteenth and Sixteenth Reports of Proceedings of the American Railway Master Mechanics' Association.

From Hamilton Smith, Jr., London, England:
Costs of Mining and Milling "Tin" Gold Ores.

From Oberlin Smith, Bridgeton, N. J.:
Flow of Metals in the Drawing Process.

From Smithsonian Institution, Washington, D. C.:
Annual Report of the Board of Regents of the Smithsonian Institution for the Year 1884.

From Societe pour la Defense des Interests de la Valée de la Seine, Rouen, France:
Memoire sur les Ameeliorations et Apporter ad Port du Havre it dans L'estuaire de la Seine.

From A. W. Stedman, Chief Engineer Lehigh Valley Railroad, Mauch Chunk, Pa.:
A framed picture showing sections of the Vosburg Tunnel, as constructed on the line of the Lehigh Valley Railroad.

From F. P. Stearns, Boston, Mass.:
Seventh Annual Report of the State Board of Health, Lunacy and Charity of Massachusetts. 1886.

From Simon Stevens, New York City:
How Steam May be Used on Canals. Letter of Simon Stevens, President Tehuantepec Railway Company, to the Canal Board of the State of New York, August 31st, 1872.

From Waterman Stone, Providence, R. I.:
Annual Report of the Commissioner of Dams and Reservoirs for the Years from 1883 to 1886, inclusive.

From Superintendent of the Library and War Records, Navy Department, Washington, D. C.:
Regulations Governing the Uniform of Commissioned Officers, Warrant Officers and Enlisted Men of the Navy of the United States, with Plates for 1886.

From Russell Thayer, Philadelphia, Pa.:
A Scientific Investigation of the Method of Action of Earthquakes and a Theory of their Primary Cause.

From J. Nelson Tubbs, Rochester. N. Y.:
Tenth Annual Report of the Executive Board of the City of Rochester, N. Y.

From the Under Secretary of State for India, India Office, London, England.
Notes on the Jumna Canal. E. T. Atkinson.
Notes on the Ganges Canal. E. T. Atkinson.
Notes on the Lower Ganges Canal. E. T. Atkinson.
Report on Remodeling the Ganges Canal, with Plans and Report of Committee. Captain Crofton.
Report on the Sardah Canal Project.
Report on the Irrigation, etc., of the Rajahmundry District. Major Cotton. 1850.
Western Jumna and Doub Canals Irrigation Works. 1851.
Copies or Extracts of Documents Referring to the Works of Irrigation of the Godavery River and Kistnah Annicuts in the Presidency of Madras 1852.
Effects of Godavery and Kistnah Annicuts, etc. Session 1859.
Report by Colonel Colton on Canal Works, etc.
Godavery River. Letters by Captain Haig, 1850.
Correspondence with India, Madras and Bombay, with Reports on Irrigation Works, Financial Results and Management. 1870.
Report of Select Committee on East India Public Works. 1878.
Index to the Report from the Select Committee on East India Public Works. 1878.
Report of Select Committee on East India Public Works. 1878-79.
Index to the Report from the Select Committee on East India Public Works. 1878-79.
Report of Famine Commission, Appendix V. Irrigation as a protection against Famine. 1881.
Resolution by the Honorable The Lieutenant-Governor of the Northwestern Provinces on the Report of the Ganges Canal Committee.

Report of the Ganges Canal Committee.

From United States Geological Survey, Washington, D. C.:

Bulletins of the United States Geological Survey, Nos. 27, 28 and 29.

Twenty Atlas Sheets United States Geological Survey.

From Robert Van Buren, Brooklyn, N. Y.:

Annual Report of the Department of City Works of the City of Brooklyn, for the year 1885.

From D. Van Nostrand, New York City:

The Separate System of Sewerage; its Theory and Construction.

From United States Navy Department, Washington, D. C.:

Annual Report of the Secretary of the Navy for the year 1886.

From Lieutenant A.W. Vogdes, U. S. A., New York City:

Description of a New Crustacean from the Clinton Group of Georgia, with remarks upon others.

From Leo Von Rosenberg, New York City:

Map showing the Mackay-Bennett Cables in the Vicinity of the Principal Fishing Grounds.

From A. M. Wellington, New York City:

Map of the preliminary located line of the Mountain Grade from Rinconada to Las Vigas in Mexico.

Map of the same showing contour lines, profile of first mile and of the preliminary located line on the upper Mountain Grade from Jalapa to Las Vigas.

Profile of the whole line.

Map of the Mexican National Railway.

From John Whitelaw, Cleveland, Ohio:

Thirteenth Annual Report of the Water-works Trustees of the City of Cleveland, Ohio, for the year ending December 31st, 1885 Parts I and II.

From other sources:

Advertisements, specifications and proposals, as follows:

For Laying Submerged Iron Sewer Pipe.

For Building Retaining Walls for Main Sewer Outlet at foot of Marsh street, Newport, R. I.

For Furnishing Iron Sewer Pipes.

Report of Hon. W. J. McAlpine and Kivas Tully, Civil Engineer, on a System of Intercepting and Outfall Sewers for the City of Toronto.

Goulard-Gibbs System of Electrical Distribution.

Resolutions of the American Shipping Convention held at Pensacola, Fla., November 1st, 1886.

On a Proposal for an American Academy of Engineering. William E. Kent.

Irrigation. Development, History, Customs, Laws and Administrative Systems relating to Irrigation, Water-courses and Waters in France, Italy and Spain. Wm. Ham Hall.

An Appeal in behalf of the Navy and its *personnel*, with notes of some incidents in its history.

Argument of Nathaniel C. Moak on the resolution to inquire as to article written by George F. Spinney for *New York Times* of April 5th, 1886, on Senator Raines, charging an effort to steal the Staten Island water front for the Baltimore and Ohio Railroad.

Official Guide to the International Health Exhibition.

Argument of Nathaniel C. Moak before the Senate Committee on Privileges and Elections, May 10th, 1883.

Plans and Proposals for the Metropolitan Water Company of the City of New York.

Report of the Sewer Committee of the City of Schenectady, including the Ordinance and Specifications regulating their use.

Memoir sur les Ameliorations et Apporter un Port du Havre et dans l'estuaire de la Seine.

Official Guide to the International Invention Exhibition, London, England.

LIST OF MEMBERS.

ADDITIONS.

MEMBERS.	Date of Election.
BRINCKERHOFF, ALEXANDER GORDON.....(Care Bates & Johnson) 114 Leonard st., New York City...	Nov. 3, 1883.
BUTTERFIELD, FRANCIS EAVE....Chief Engineer Mexican Guadalupe R. R., Villadama, Nuevo Leon, Mexico.....	Sept. 1, 1886.

ASSOCIATE. Date of Election.

HASKINS, WILLIAM JEWETT. ....(Elected Junior March 7th, 1883.) Assistant Engineer Departm't Public Works, 537 West 105th st., New York City. .....Dec. 1, 1886.

MORRIS, THOMAS O'NEIL. .....Engineer Maintenance Way Cincinnati, Indianapolis, St. Louis and Chicago Ry., Indianapolis, Ind.....Oct. 6, 1886.

RICHARDS, HUGH TUDOR. .....Resident Engineer Sonora R. R., Guaymas, Mexico.....Oct. 6, 1886.

WARD, JOHN FROTHINGHAM. .....Consulting Engineer, 18 Broadway, New York City.....Oct. 6, 1886.

WETHERILL, WILLIAM CHATLIN. Liberty, Mo. .....Dec. 1, 1886.

JUNIOR.

MODJESKI, RALPH.....Assistant Engineer Omaha Bridge, Omaha, Neb.....Dec. 1, 1886.

CHANGES AND CORRECTIONS.

MEMBERS.

ALLEN, C. FRANK .....Las Vegas, N. M.

ANDERSON, ADNA .....Second Vice-President and Engineer-in-Chief Northern Pacific R. R., Tacoma, Wash.

APPLETON, ELLERY C .....Resident Engineer Chicago, Kansas and Nebraska Ry., Marion, Kan.

BARNARD, AUGUSTUS P.....28 West 20th st., New York City.

BLICKENSDERFER, JACOB .....Consulting Engineer Union Pacific Ry., Omaha, Neb.

BOGUE, VIRGIL G .....Chief Engineer Union Pacific Ry., Omaha, Neb.

BONZANO, MAXIMILIAN F.....Superintendent No. 1 Penn. and Bound Brook Division Philadelphia and Reading R. R., 9th and Green sts., Philadelphia, Pa.

CALKINS, FRANK A. .....55 Ross st., Brooklyn, N. Y.

CRAIG, CHAMBERS M. .....Alabama Midland R. R., Sneads, Fla.

CRAIGHILL, WILLIAM P.....Col. Corps of Engineers U. S. A., 1734 St. Paul st., Baltimore, Md.

CUNNINGHAM, DAVID W .....308 Garrard st., Covington, Ky.

CURTIS, WENDELL R. .....Assistant Engineer Toledo, St. Louis and Kansas City R. R., 56 Elm st., Toledo, Ohio.

FIRMSTONE, FRANK.....Easton, Pa.

FULLER, FRANKLIN I.....Room 33, Portland Savings Bank Building, Portland, Oregon.

HINCKLEY, JOHN F. .....Chief Engineer St. Louis, Arkansas and Texas R. R., Texarkana, Texas.
HOLMAN, MINARD L.....3744 Finney Ave., St. Louis, Mo.
KINSLEY, THOMAS P.....Amherst, Mass.
LATCHA, JACOB A.....Chief Engineer Duluth, South Shore and Atlantic Ry., Marquette, Mich.
LEDERLE, GEORGE A. .....915 South 5th st., Omaha, Neb.
MASTEN, CORNELIUS S.....Engineer Mariopa and Phoenix R. R., Phoenix, Arizona.
MCKEE, SAMUEL B.....Division Engineer Canadian Pacific Ry., Greenville, Maine.
MOORE, CHARLES E .....Assistant Engineer Southern Pacific Ry., Santa Clara, Cal.
NOURSE, EDWIN G.....Room 721, Rialto Building, Chicago, Ill.
PARKHURST, HENRY W. .....Room 311, Home Insurance Building, Chicago, Ill.
PETRY, ALFRED .....911 Scott st., Covington, Ky.
PHINNEY, HENRY W. B.....San Diego, Cal.
POST, JAMES C.....Major Corps of Engineers U. S. A., Cincinnati, Ohio.
[illegible]ON, CHARLES D.....St. Louis, Arkansas and Texas Ry., Texarkana, Texas.
S[illegible]DERSON, J. GARDNER. .....125 East 86th st., New York City.
SAVAGE, ALBERT C. .....(Care Superintendent New York and Honduras Rosario Mining Company.) San Juancinto, Honduras, Central America.
SCOTT, ARTHUR H.....Wayne County Savings Bank Building, Detroit, Mich.
SEYMOUR, CHARLES.....Division Engineer Louisville and Nashville R. R., Florence, Ala.
SHINN, WILLIAM P. .....Vice-President New York and New England R. R., Boston, Mass.
SKILTON, GEORGE S .....52 Columbia Heights, Brooklyn, N. Y.
SMITH, ISAAC W. .....Engineer Water Commission, Portland, Oregon.
SNOW, J. PARKER .....Orlando, Fla.
VAN BROCKLIN, MARTIN.....Capes Chambers, Bond st., Sidney, New South Wales, Australia.
WADDELL, JOHN A. L.....Consulting Engineer, Representative Phœnix Bridge Company and Phœnix Iron Company, 118 West 6th st., Kansas City, Mo.
WALKER, WILLIAM W .....Chief Engineer and General Manager Arizona Narrow Gauge R. R., Cedar Rapids, Iowa.
WALLACE, JOHN F .....Keithsburg, Ill.
WEEKS, HARVEY R. .....Resident Engineer Chicago, Santa Fé and California Ry., Kahoma, Mo.
WELLINGTON, ARTHUR M. .....Editor *Engineering News*, Tribune Building, New York City.

ASSOCIATE.

HARRIS, CHARLES M. ..... White Plains, N. Y.

JUNIORS.

ABBOTT, ARTHUR V. ..... Closter, N. J.
BOOKER, BERNARD F. ..... Assistant Engineer Chicago, Santa Fé and California R. R., 1214 Main st., Kansas City, Mo.
DONOVAN, JOHN J. ..... Assistant Engineer in Charge Cascade Division Northern Pacific R. R., Eagle Gorge *via* Melrose P. O., Wash.
EDES, WILLIAM C. ..... Yreka, Cal.
FERRER, CARLOS F. ..... 39 Broad st., New York City.
GLADDING, HENRY H. ..... 30 Stanley st., New Haven, Conn.
GOLDMARK, HENRY ..... Union Bridge Company, Athens, Pa.
JOHNSON, SINCLAIR J. ..... 102 East Rayen Ave., Youngstown, Ohio.
MILLS, CHARLES M. ..... Phœnixville, Pa.
NOYES, ELLIS B. ..... Division Engineer's Office New York Canals, Syracuse, N. Y.
PARSONS, W. BARCLAY, Jr. ..... Chief Engineer Fort Worth and Rio G Ry., Fort Worth, Texas.
RICKER, GEORGE A. ..... Room 82, White Building, Buffalo, N. Y.
SANFORD, DAVID C. ..... South Norwalk, Conn.
SHEPARD, WILLIAM T. ..... Bristol, Conn.
TRATMAN, E. E. RUSSELL ..... 144 Remsen st., Brooklyn, N. Y.
WADDELL, MONTGOMERY ..... (Care Edison Electric Light Company.) Schenectady, N. Y.
WHISTLER, THOMAS D. ..... 7 East 41st st., New York City.

RESIGNATIONS.

BISHOP, JUDSON W. ..... Dec. 31, 1886.
CASEY, THOMAS L. ..... Dec. 31, 1886.
NICHOLS, AURIN B. ..... Dec. 31, 1886.
TRAFTON, GILMAN ..... Dec. 31, 1886.
WOOD, DE VOLSON. ..... Dec. 31, 1886.

DEATHS.

DIRKS, JUSTUS ..... Elected Honorary Member June 2, 1880; died December 26, 1886.
SMITH, C. SHALER ..... Elected Member March 5, 1873; died December 19, 1886.

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